Waikawa Estuary Synoptic Intertidal and Subtidal Survey 2017-18

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Waikawa Estuary

Synoptic Intertidal and Subtidal Survey 2017/18

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for

**Horizons
Regional
Council**

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Cover Photo: Waikawa Estuary, view over the main lower estuary channel towards Kapiti Island, March 2018.


Waikawa Estuary, looking north east towards the middle reaches at high tide

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WAIKAWA ESTUARY - EXECUTIVE SUMMARY

Waikawa Estuary is a relatively modified, moderate sized (16 ha), shallow (mean depth ~0.5-1 m at high water), often poorly-flushed tidal river type estuary. It has a single tidal opening that may occasionally be restricted, a central river channel, and a larger, sand-dominated basin in the lower estuary. The catchment is dominated by native forest and pasture. It is one of the key estuaries in Horizons Regional Council's (HRC's) long-term coastal monitoring programme. This report presents the results of the March 2018 synoptic estuary survey with broad scale intertidal and subtidal channel monitoring results, overall estuary condition and issues, and monitoring recommendations summarised below.

SYNOPTIC SURVEY RESULTS

- Intertidal flats comprised 40.7 % of the estuary, saltmarsh 9.8 %, and subtidal waters 49.5 %.
- Intertidal substrates (outside of saltmarsh) were dominated by firm sand (61.9 %) and firm muddy sand (21.8 %) with smaller areas of firm sand (10.8 %), and soft mud (4 %).
- Opportunistic macroalgae were absent from the estuary (<1% of the available intertidal habitat - an Ecological Quality Rating of "HIGH"), no gross eutrophic zones were present, and phytoplankton (chlorophyll *a*) concentrations were very low in subtidal waters of the main estuary channel.
- Seagrass was present within the main estuary channel, but was absent from intertidal habitat.
- Constricted to middle estuary reaches, saltmarsh cover was relatively extensive 1.6 ha (19.4 % of the intertidal area) and was comprised of herbfields (31 %), rushland (12 %) and sedgeland (57 %).

ESTUARY CONDITION AND ISSUES

In relation to the key issues addressed by the broad scale monitoring (i.e. muddiness, eutrophication, and habitat modification), the March 2018 synoptic survey results show that the estuary supported a variety of substrate types, relatively extensive areas of saltmarsh, but no seagrass. Sediments were sand-dominated (<5 % of intertidal area in soft muds), well oxygenated and there were no intertidal nuisance macroalgal growths, or subtidal phytoplankton blooms despite above threshold nutrient concentrations and poor sediment conditions in the mid-upper main estuary channel.

The combined results place the estuary in a "MODERATE" state overall in relation to ecological health, with an ETI score of 0.85, Band D, reflecting a high degree of eutrophic symptoms. This latter rating was primarily driven by the presence of elevated (surface water) phytoplankton biomass measured monthly over the 2017/18 (Nov-March) summer period at a representative site within the main estuary channel.

RECOMMENDED MONITORING

Waikawa Estuary has been identified by HRC as a priority for monitoring because it is an estuary with high ecological and human use values that is situated in a developed catchment, and therefore vulnerable to excessive sedimentation and eutrophication. As a consequence, it is a key part of HRC's coastal monitoring programme being undertaken throughout the Manawatu-Wanganui region. The first screening-level (synoptic) assessment of intertidal and subtidal habitat state has now been undertaken (March 2018).

Given the previous presence of eutrophic symptoms in the main channel of the esutary (i.e. in February 2016 and summer 2017/18), to assess the presence of eutrophication (including both benthic and water column effects), it is recommended that monitoring (annually for the first three years to establish a baseline and thereafter at 5 yearly intervals) be focused on prolonged low-flow conditions during the growing season (November-April) and include an identical sampling protocol to that used in this report. This proposed schedule will also be useful in confirming that this low risk estuary has not changed its risk rating in coming years. The next synoptic survey of Waikawa Estuary is therefore recommended for 2019.

1. INTRODUCTION

Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. A long-term objective of the Horizons Regional Council (HRC) is to incorporate all significant estuaries within their State of Environment monitoring framework through implementation of the NZ National Estuary Monitoring Protocol (NEMP, Robertson et al. 2002). While the region's estuaries have received relatively little attention, the Department of Conservation funded broad scale habitat mapping of the Whanganui River Estuary in 2009 (Stevens and Robertson 2009), and in late 2015 HRC commissioned an Ecological Vulnerability Assessment for all of the estuaries within the region to assess sediment and eutrophication risks, map dominant habitat features, and provide the Council with defensible monitoring recommendations and priorities (Robertson and Stevens 2016). The estuaries currently included in the programme are; Manawatu Estuary, Rangitikei Estuary, Waikawa Estuary and Ohau Estuary.

Monitoring of the Waikawa Estuary began with preliminary synoptic broad scale survey undertaken in February 2016 and the first year of comprehensive synoptic monitoring undertaken in March 2018.

Within NZ, the approach for monitoring estuary condition follows the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002) and the NZ Estuary Trophic Index (ETI) (Robertson et al. 2016a and b). It consists of three components as follows:

1. **Ecological Vulnerability Assessment (EVA**) of estuaries in the region to major issues (see Table 1) and appropriate monitoring design. This component has been partially undertaken (includes assessment of vulnerabilities to sediment and eutrophication only but excludes other coastal resources and pressures), and is reported on in Robertson and Stevens (2016).
2. **Broad Scale Habitat Mapping (NEMP approach).** This component (see Table 1) maps the key habitats within the estuary, determines their condition, and assesses changes to these habitats over time. Preliminary screening-level (synoptic) broad scale intertidal mapping of Waikawa Estuary was first undertaken in February 2016 in tandem with the EVA (Robertson and Stevens 2016).
3. **Fine Scale Monitoring (Synoptic survey and NEMP approach).** Monitoring of selected physical and chemical characteristics (see Table 1). This component provides detailed information on the condition of the Waikawa Estuary. The current report describes the first year comprehensive baseline survey of the condition of the estuary's two main habitat types (water column and underlying substrata) undertaken in March 2018.

Report Structure: The current report presents an overview of key estuary issues in NZ and recommended monitoring indicators (Section 1). This is followed by risk indicator ratings (Section 2) and the sampling methods (Section 3) used in this synoptic assessment. Summarised results of the March 2018 field sampling are then presented and discussed (Section 4) for the following:

- Broad scale mapping of estuary sediment types.
- Broad scale mapping of macroalgal (e.g. *Ulva* (sea lettuce), *Gracilaria* sp.) and seagrass beds (e.g. *Zostera muelleri*).
- Broad scale mapping of saltmarsh vegetation.
- Fine scale assessment of conditions within the main estuary channel (including both water column and underlying substrata).

To aid interpretation of the findings, results are related to relevant risk indicator ratings to facilitate the assessment of overall estuary condition (summarised in Section 5), and to guide monitoring recommendations (Section 6).

WAIKAWA ESTUARY

The Waikawa Estuary (16 ha) is a moderate length, shallow, often poorly-flushed tidal river estuary (SSRTRE) that has a moderate freshwater inflow, extends approximately 2 km inland, and is located at Waikawa township (Figure 1). Its main channel, which comprises a large proportion (49.5 %) of the estuary, can become stratified, largely confined within the main river channel and is characterised by low salinity surface waters. The upper estuary is flanked by reclaimed pasture, whereas the middle and lower reaches have intertidal flats and small areas of saltmarsh. Beach duneland vegetation, primarily spinifex (*Spinifex sericeus*) and marram grass (*Ammophila arenaria*), dominates the terrestrial margins near the beach. The estuary mouth is mostly open to the sea but can become restricted and consequently the estuary is often brackish. The estuary has Kai Tahu cultural and spiritual values, and its estuarine values include intertidal flats used as feeding and roosting areas for birds and fish nursery habitat. Although the natural vegetated margin is mostly lost and much of the upper estuary channelised, habitat diversity is moderate-high. Catchment landuse is dominated by native forest (35 %), sheep and beef grazing (26 %) and dairy (23 %) on high and low producing exotic grassland but it also includes significant areas of exotic forest (13 %).

The estuary has low to moderate vulnerability to muddiness issues based on the facts that the current suspended sediment load (CSSL) is <5 times the estimated natural state SS load (NSSL), and that the estuary is dominated by muds particularly in the mid-upper estuary, with sands dominating the lower reaches. However, it is moderately to highly susceptible to eutrophication at times based on; its poorly flushed nature (the upper estuary experiences salinity stratification during stable baseflows, i.e. salt wedge effect and the mouth is often restricted) and its high nutrient load (current estimated catchment N areal loading of 1195 mg N m^{-2} d^{-1} exceeds the tentative guideline for high susceptibility SSRTRE estuaries of ~250 mg N m^{-2} d^{-1}; Robertson et al. 2016). During low flows when the estuary is stratified, nuisance algal/macrophyte growth may occur (Robertson and Stevens 2016). The presence of elevated chlorophyll *a* concentrations at times may be attributable to phytoplankton blooms in saline bottom waters and from freshwater sources upstream of the estuary.

Table 1. Summary of the major environmental issues affecting most New Zealand estuaries.

1. Sediment Changes

Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays (Black et al. 2013). Prior to European settlement they were dominated by sandy sediments and had low sedimentation rates (<1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, New Zealand's estuaries have begun to infill rapidly with fine sediments. Today, average sedimentation rates in our estuaries are typically 10 times or more higher than before humans arrived (e.g. see Abrahim 2005, Gibb and Cox 2009, Robertson and Stevens 2007, 2010, and Swales and Hume 1995). Soil erosion and sedimentation can also contribute to turbid conditions and poor water quality, particularly in shallow, wind-exposed estuaries where re-suspension of fine sediments is common. These changes to water and sediment result in negative impacts to estuarine ecology that are difficult to reverse. They include;

- habitat loss such as the infilling of saltmarsh and tidal flats,
- prevention of sunlight from reaching aquatic vegetation such as seagrass meadows,
- increased toxicity and eutrophication by binding toxic contaminants (e.g. heavy metals and hydrocarbons) and nutrients,
- a shift towards mud-tolerant benthic organisms which often means a loss of sensitive shellfish (e.g. pipi) and other filter feeders; and
- making the water unappealing to swimmers.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Sediment Changes	Soft Mud Area	GIS Based Broad scale mapping - estimates the area and change in soft mud habitat over time.
	Seagrass Area/biomass	GIS Based Broad scale mapping - estimates the area and change in seagrass habitat over time.
	Saltmarsh Area	GIS Based Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
	Mud Content	Grain size - estimates the % mud content of sediment.
	Water Clarity/Turbidity	Secchi disc water clarity or turbidity.
	Sediment Toxicants	Sediment heavy metal concentrations (see toxicity section).
	Sedimentation Rate	Fine scale measurement of sediment infilling rate (e.g. using sediment plates).
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

2. Eutrophication

Eutrophication is a process that adversely affects the high value biological components of an estuary, in particular through the increased growth, primary production and biomass of phytoplankton, macroalgae (or both); loss of seagrass, changes in the balance of organisms; and water quality degradation. The consequences of eutrophication are undesirable if they appreciably degrade ecosystem health and/or the sustainable provision of goods and services (Ferriera et al. 2011). Susceptibility of an estuary to eutrophication is controlled by factors related to hydrodynamics, physical conditions and biological processes (National Research Council, 2000) and hence is generally estuary-type specific. However, the general consensus is that, subject to available light, excessive nutrient input causes growth and accumulation of opportunistic fast growing primary producers (i.e. phytoplankton and opportunistic red or green macroalgae and/or epiphytes - Painting et al. 2007). In nutrient-rich estuaries, the relative abundance of each of these primary producer groups is largely dependent on flushing, proximity to the nutrient source, and light availability. Notably, phytoplankton blooms are generally not a major problem in well flushed estuaries (Valiela et al. 1997), and hence are not common in the majority of NZ estuaries. Of greater concern are the mass blooms of green and red macroalgae, mainly of the genera *Cladophora, Ulva,* and *Gracilaria* which are now widespread on intertidal flats and shallow subtidal areas of nutrient-enriched New Zealand estuaries. They present a significant nuisance problem, especially when loose mats accumulate on shorelines and decompose, both within the estuary and adjacent coastal areas. Blooms also have major ecological impacts on water and sediment quality (e.g. reduced clarity, physical smothering, lack of oxygen), affecting or displacing the animals that live there (Anderson et al. 2002, Valiela et al. 1997).

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Eutrophication	Macroalgal Cover/Biomass	Broad scale mapping - macroalgal cover/biomass over time.
	Phytoplankton (water column)	Chlorophyll a concentration (water column).
	Sediment Organic and Nutrient Enrichment	Chemical analysis of sediment total nitrogen, total phosphorus, and total organic carbon concentrations.
	Water Column Nutrients	Chemical analysis of various forms of N and P (water column).
	Redox Profile	Redox potential discontinuity profile (RPD) using visual method (i.e. apparent Redox Potential Depth - aRPD) and/or redox probe. Note: Total Sulphur is also currently under trial.
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

Table 1. Summary of major environmental issues affecting New Zealand estuaries (continued).

3. Disease Risk

Runoff from farmland and human wastewater often carries a variety of disease-causing organisms or pathogens (including viruses, bacteria and protozoans) that, once discharged into the estuarine environment, can survive for some time (e.g. Stewart et al. 2008). Every time humans come into contact with seawater that has been contaminated with human and animal faeces, we expose ourselves to these organisms and risk getting sick. Human diseases linked to such organisms include gastroenteritis, salmonellosis and hepatitis A (Wade et al. 2003). Aside from serious health risks posed to humans through recreational contact and shellfish consumption, pathogen contamination can also cause economic losses due to closed commercial shellfish beds.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Disease Risk	Shellfish and Bathing Water faecal coliforms, viruses, protozoa etc.	Bathing water and shellfish disease risk monitoring (Council or industry driven).

4. Toxic Contamination

In the last 60 years, NZ has seen a huge range of synthetic chemicals introduced to the coastal environment through urban and agricultural stormwater runoff, groundwater contamination, industrial discharges, oil spills, antifouling agents, leaching from boat hulls, and air pollution. Many of them are toxic even in minute concentrations, and of particular concern are polycyclic aromatic hydrocarbons (PAHs), heavy metals, polychlorinated biphenyls (PCBs), endocrine disrupting compounds, and pesticides. When they enter estuaries these chemicals collect in sediments and bio-accumulate in fish and shellfish, causing health risks to marine life and humans. In addition, natural toxins can be released by macroalgae and phytoplankton, often causing mass closures of shellfish beds, potentially hindering the supply of food resources, as well as introducing economic implications for people depending on various shellfish stocks for their income. For example, in 1993, a nationwide closure of shellfish harvesting was instigated in NZ after 180 cases of human illness following the consumption of various shellfish contaminated by a toxic dinoflagellate, which also lead to wide-spread fish and shellfish deaths (de Salas et al. 2005). Decay of organic matter in estuaries (e.g. macroalgal blooms) can also cause the production of sulphides and ammonia at concentrations exceeding ecotoxicity thresholds.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Toxins	Sediment Contaminants	Chemical analysis of heavy metals (total recoverable cadmium, chromium, copper, nickel, lead and zinc) and any other suspected contaminants in sediment samples.
	Biota Contaminants	Chemical analysis of suspected contaminants in body of at-risk biota (e.g. fish, shellfish).
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

5. Habitat Loss

Estuaries have many different types of high value habitats including shellfish beds, seagrass meadows, saltmarshes (rushlands, herbfields, reedlands etc.), tidal flats, forested wetlands, beaches, river deltas, and rocky shores. The continued health and biodiversity of estuarine systems depends on the maintenance of high-quality habitat. Loss of such habitat negatively affects fisheries, animal populations, filtering of water pollutants, and the ability of shorelines to resist storm-related erosion. Within New Zealand, habitat degradation or loss is common-place with the major causes being sea level rise, population pressures on margins, dredging, drainage, reclamation, pest and weed invasion, reduced flows (damming and irrigation), over-fishing, polluted runoff, and wastewater discharges (IPCC 2007 and 2013, Kennish 2002).

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Habitat Loss	Saltmarsh Area	Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
	Seagrass Area	Broad scale mapping - estimates the area and change in seagrass habitat over time.
	Vegetated Terrestrial Buffer	Broad scale mapping - estimates the area and change in buffer habitat over time.
	Shellfish Area	Broad scale mapping - estimates the area and change in shellfish habitat over time.
	Unvegetated Habitat Area	Broad scale mapping - estimates the area and change in unvegetated habitat over time, broken down into the different substrate types.
	Sea level	Measure sea level change.
	Others e.g. Freshwater Inflows, Fish Surveys, Floodgates, Wastewater Discharges	Various survey types.

Figure 1. Waikawa Estuary, showing main estuary zones and subtidal channel water and sediment quality monitoring sites assessed in 2018. Image source: Google Earth Pro (dated 29 July 2017).

2. ESTUARY RISK INDICATOR RATINGS

The estuary monitoring approach used by Wriggle has been established to provide a defensible, cost-effective way to help quickly identify the likely presence of the predominant issues affecting NZ estuaries (i.e. eutrophication, sedimentation, disease risk, toxicity and habitat change; Table 1), and to assess changes in the long term condition of estuarine systems. The design is based on the use of primary indicators that have a documented strong relationship with water or sediment quality.

In order to facilitate this assessment process, "risk indicator ratings" have also been proposed that assign a relative level of risk (e.g. very low, low, moderate, high) of specific indicators adversely affecting intertidal estuary condition (see Table 2 below). Each risk indicator rating is designed to be used in combination with relevant information and other risk indicator ratings, and under expert guidance, to assess overall estuarine condition in relation to key issues, and make monitoring and management recommendations. When interpreting risk indicator results we emphasise:

- The importance of taking into account other relevant information and/or indicator results before making management decisions regarding the presence or significance of any estuary issue e.g. community aspirations, cost/benefit considerations.
- That rating and ranking systems can easily mask or oversimplify results. For instance, large changes can occur within the same risk category, but small changes near the edge of one risk category may shift the rating to the next risk level.
- Most issues will have a mix of primary and supporting indicators, primary indicators being given more weight in assessing the significance of results. It is noted that many supporting estuary indicators will be monitored under other programmes and can be used if primary indicators reflect a significant risk exists, or if risk profiles have changed over time.
- Ratings have been established in many cases using statistical measures based on NZ estuary data and presented in the NZ estuary Trophic Index (NZ ETI; Robertson et al. 2016a and 2016b). However, where such data is lacking, or has yet to be processed, ratings have been established using professional judgement, based on our experience from monitoring numerous NZ estuaries. Our hope is that where a high level of risk is identified, the following steps are taken:
    1. Statistical measures be used to refine indicator ratings where information is lacking.
    2. Issues identified as having a high likelihood of causing a significant change in ecological condition (either positive or negative), trigger intensive, targeted investigations to appropriately characterise the extent of the issue.
    3. The outputs stimulate discussion regarding what an acceptable level of risk is, and how it should best be managed.

A subset of the indicators and interim risk ratings used for the Waikawa Estuary synoptic monitoring programme are summarised in Table 2, with supporting notes explaining the use and justifications for each indicator in Appendix 2. The basis underpinning most of the ratings is the observed correlation between an indicator and the presence of degraded estuary conditions from a range of tidal lagoon and tidal river estuaries throughout NZ. Work to refine and document these relationships is ongoing.

Table 2. Summary of estuary condition risk indicator ratings used where appropriate in the present report.

RISK INDICATOR RATINGS / ETI BANDS (indicate risk of adverse ecological impacts)				
BROAD AND FINE SCALE INDICATORS	Very Low - Band A	Low - Band B	Moderate - Band C	High - Band D
Soft mud (% of unvegetated intertidal substrate)*	<1%	1-5%	>5-15%	>15%
Sediment Mud Content (%mud)*	<5%	5-10%	>10-25%	>25%
Apparent Redox Potential Discontinuity (aRPD)**	Unreliable	Unreliable	0.5-2cm	<0.5cm
Redox Potential (RP mV) upper 3cm***	>+100mV	+100 to -50mV	-50 to -150mV	<-150mV
Sediment Oxygenation (aRPD <0.5cm or RP@3cm <-150mV)*	<0.5ha or <1%	0.5-5ha or 1-5%	6-20ha or >5-10%	>20ha or >10%
Macroalgal Ecological Quality Rating (OMBT)*	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	0.0 - <0.4
Seagrass (% change from baseline)	<5% decrease	5%-10% decrease	>10-20% decrease	>20% decrease
Gross Eutrophic Zones (ha or % of intertidal area)	<0.5ha or <1%	0.5-5ha or 1-5%	6-20ha or >5-10%	>20ha or >10%
Saltmarsh Extent (% of intertidal area)	>20%	>10-20%	>5-10%	0-5%
Supporting indicator **Extent** (% remaining from est. natural state)	>80-100%	>60-80%	>40-60%	<40%
Vegetated 200m Terrestrial Margin	>80-100%	>50-80%	>25-50%	<25%
Percent Change from Monitored Baseline	<5%	5-10%	>10-20%	>20%
NZ ETI score*	0-0.25	0.25-0.50	0.50-0.75	0.75-1.0

*NZ ETI (Robertson et al. 2016b), **Hargrave et al. (2008), ***Robertson (PhD under examination), Keeley et al. (2012). See NOTES in Appendix 2 for further information.

3. METHODS

Broad-scale mapping is a method for describing habitat types based on the dominant surface features present (e.g. substrate: mud, sand, cobble, rock; or vegetation: macrophyte, macroalgae, rushland, etc). It follows the NEMP approach originally described for use in NZ estuaries by Robertson et al. (2002) with a combination of detailed ground-truthing of aerial photography, and GIS-based digital mapping from photography to record the primary habitat features present. Appendix 1 lists the definitions used to classify substrate and saltmarsh vegetation. Very simply, the method involves:

- Obtaining aerial photos of the estuary for recording dominant habitat features.
- Carrying out field identification and mapping (i.e. ground-truthing) using laminated aerial photos.
- Digitising ground-truthed features evident on aerial photographs into GIS layers (e.g. ArcMap).

The georeferenced spatial habitat maps provide a robust baseline of key indicators that are used with risk ratings to assess estuary condition in response to common stressors, and assess future change.

Estuary boundaries were set seaward from an imaginary line closing the mouth to the upper extent of saline intrusion (i.e. where ocean derived salts during average annual low flow are <0.5 ppt). For the current study, rectified colour aerial images (~0.25 m/pixel resolution) dated 29 July 2017 were sourced from Google Earth Pro (7.3.1.4507 64-bit), and used by experienced scientists who walked the area on 6 March 2018 (when the mouth was open to the sea) to ground-truth the spatial extent of dominant vegetation and substrate types (Figure 3). When present, macroalgae and seagrass patches were mapped to the nearest 5 % using a 6 category percent cover rating scale as a guide to describe density (see Figure 2). Notes on sampling, resolution and accuracy are presented in Appendix 3.

Macroalgae was further assessed by identifying patches of comparable growth and measuring:

- % cover of opportunistic macroalgae (the spatial extent and density of algal cover providing an early warning of eutrophication issues).
- Macroalgal biomass (providing a direct measure of areas of excessive growth).
- Extent of algal entrainment in sediment (highlighting where nuisance conditions have a high potential for establishing and persisting).
- Gross eutrophic zones (highlighting significant sediment degradation by measuring where there is a combined presence of high algal cover or biomass, low sediment oxygenation, and soft muds).

Where macroalgal cover exceeds 5 % of the Available Intertidal Habitat (AIH), a modified Opportunistic Macroalgal Blooming Tool (OMBT) (UK WDF 2014) is used to rate macroalgal condition. The OMBT is a 5 part multimetric index that produces an overall Ecological Quality Rating (EQR) ranging from 0 (major disturbance) to 1 (minimally disturbed) and which is placed within overall quality status threshold bands (i.e. bad, poor, good, moderate, high). This integrated index provides a comprehensive measure of the combined influence of macroalgal growth and distribution (see Appendix 4 for additional background).

Broad scale habitat features were digitised into ArcMap 10.5 shapefiles and combined with field notes and georeferenced photographs, to produce habitat maps showing the dominant cover of: substrate, macroalgae (e.g. *Ulva* sp., *Gracilaria* sp.) and saltmarsh vegetation (Figure 4). These broad scale results are summarised in Section 4, with the supporting GIS files (supplied as a separate electronic output) providing a much more detailed data set designed for easy interrogation to address specific monitoring and management questions.

Figure 2. Visual rating scale for percentage cover estimates of macroalgae (top) and seagrass (bottom).

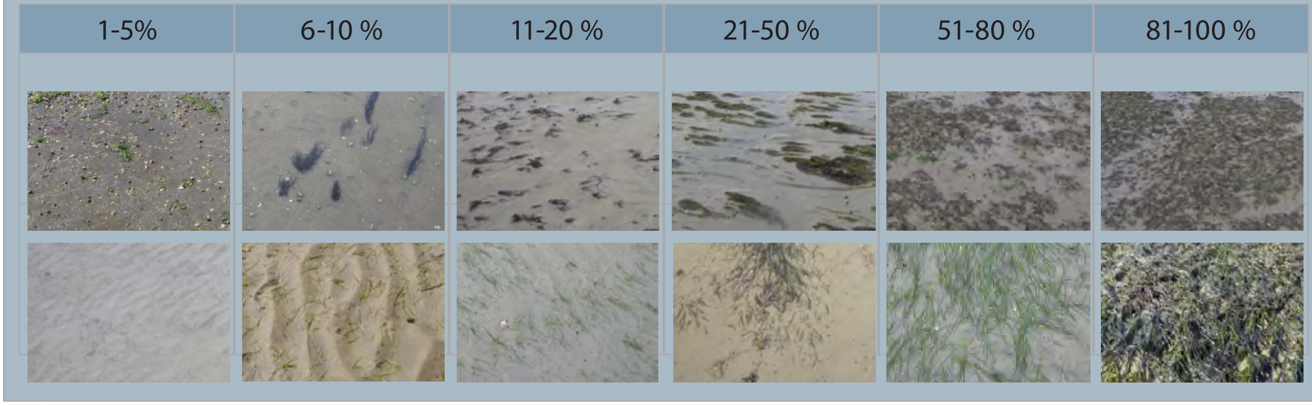


Figure 3. Waikawa Estuary 2018 - mapped estuary extent showing ground-truthing coverage.

2. METHODS (CONTINUED)

Subtidal Channel Water and Sediment Quality

To characterise conditions within the main estuary channel, three representative sites were selected in deep main channel sections in the estuary where there was a potential for the estuary water to become stratified (Sites X, Y and Z respectively, see Figure 1). At each site at high tide, a YSI-EXO1 Sonde hand-held field meter was used to directly measure and log depth, chlorophyll *a*, salinity, temperature, and dissolved oxygen in upper and lower 0.5 m of the water column. At the same locations water samples were also collected with a van dorn water sampler for laboratory nutrient analyses (total N, nitrate-N, ammonia-N, dissolved reactive P and total P concentrations).

In addition, at each site secchi disc clarity was measured and one benthic sediment sample was collected using either a remotely triggered van veen grab sampler or a custom built sediment sampling hoe with telescopic handle). Once at the surface the sediment apparent Redox Potential Discontinuity (aRPD) depth was measured and photographed, vegetation (species/% cover) noted, and a sediment sub-sample collected for subsequent chemical analysis for TOC, grain size, TN and TP.

- All samples were kept in a chilly bin in the field before dispatch to R.J. Hill Laboratories for chemical analysis (details of lab methods and detection limits in Appendix 5):
- Samples were tracked using standard Chain of Custody forms and results checked and transferred electronically to avoid transcription errors.

In an effort to coincide with prolonged low freshwater inflow conditions (i.e. likely worst case scenario with respect to eutrophication impacts), fieldwork for this component was undertaken in Waikawa Estuary on 6 March 2018.

4. RESULTS AND DISCUSSION

4.1 BROAD SCALE INTERTIDAL MAPPING SUMMARY

The 2018 broad scale habitat mapping ground-truthed and mapped all intertidal substrate and vegetation, with the five dominant estuary features summarised in Table 3 and shown in Figure 4. The estuary comprises a relatively long, narrow enclosed tidal basin near its mouth, and brackish dominated river channels to the north east where the tidal influence extends inland from the upper saline limit. It was dominated by subtidal river channel (49.5 %) and intertidal flats (40.7 %), and a smaller area of saltmarsh (9.8 %). No intertidal seagrass or dense (>50% cover) opportunistic macroalgae was observed, with a small patch of subtidal seagrass (*Ruppia* sp.) present in the middle estuary (Figure 4). The supporting GIS files underlying this written report provide a detailed spatial record of the key features present throughout the estuary. These are intended as the primary supporting tool to help the Council address a wide suite of estuary issues and management needs, and to act as a baseline to assess future change.

Comparisons between the 2016 synoptic survey and 2018 results show that 2016 results were similar to those from 2018, indicating substrate type and benthic primary producer communities in estuary have not changed significantly in the past two years.

In the following sections, various factors related to each of these key habitats (e.g. area of soft mud) are used in conjunction with risk ratings to assess key estuary issues of sedimentation, eutrophication, and habitat modification.

Table 3. Summary of dominant broad scale features in Waikawa Estuary, 2018.

Dominant Estuary Feature		2018		
		ha	% intertidal	% estuary
1.	Intertidal flats (excluding saltmarsh)	6.5	80.6	40.7
2.	Opportunistic macroalgal beds (>50 % cover) [on intertidal flats]	0	-	0
3.	Seagrass (>20 % cover) [on intertidal flats]	0	-	0
4.	Saltmarsh	1.6	19.4	9.8
5.	Subtidal waters	7.9	-	49.5
Total Estuary		**16**	**100**	**100**

4.1.1 INTERTIDAL SUBSTRATE

Results (summarised in Table 4 and Figure 5) show substrates on intertidal flats were dominated by mobile sand (61.9 %) and firm muddy sand (21.8 %) with smaller areas of firm sand (10.8 %) and soft mud (4 %). Strong tidal and freshwater flushing action in the main river channel facilitates the removal of fine material and helps to maintain sand dominated substrata throughout the estuary beds, particularly in the mid and lower estuary near the estuary entrance. Muddy sands dominate in more sheltered areas (where current flows are less pronounced), while soft muds are confined to the middle and upper tidal reaches.

Table 4. Summary of dominant intertidal substrate, Waikawa Estuary, 2018.

Dominant Substrate	Ha	%	Comments
Rock field man-made	0.1	1.4	Adjacent to main channel in lower and middle estuary
Cobble field	0.01	0.1	Small patch in lower estuary
Mobile sand	5.0	61.9	Predominantly near the entrance
Firm sand	0.9	10.8	Large areas within the main channel and near the entrance
Firm muddy sand	1.8	21.8	Situated on interidal flats throughout estuary
Soft muddy sand	0	-	-
Soft mud	0.3	4.0	Narrow bands in sheltered channels in the mid-upper estuary
Very soft mud	0	-	-
Grand Total	**8.1**	**100**	

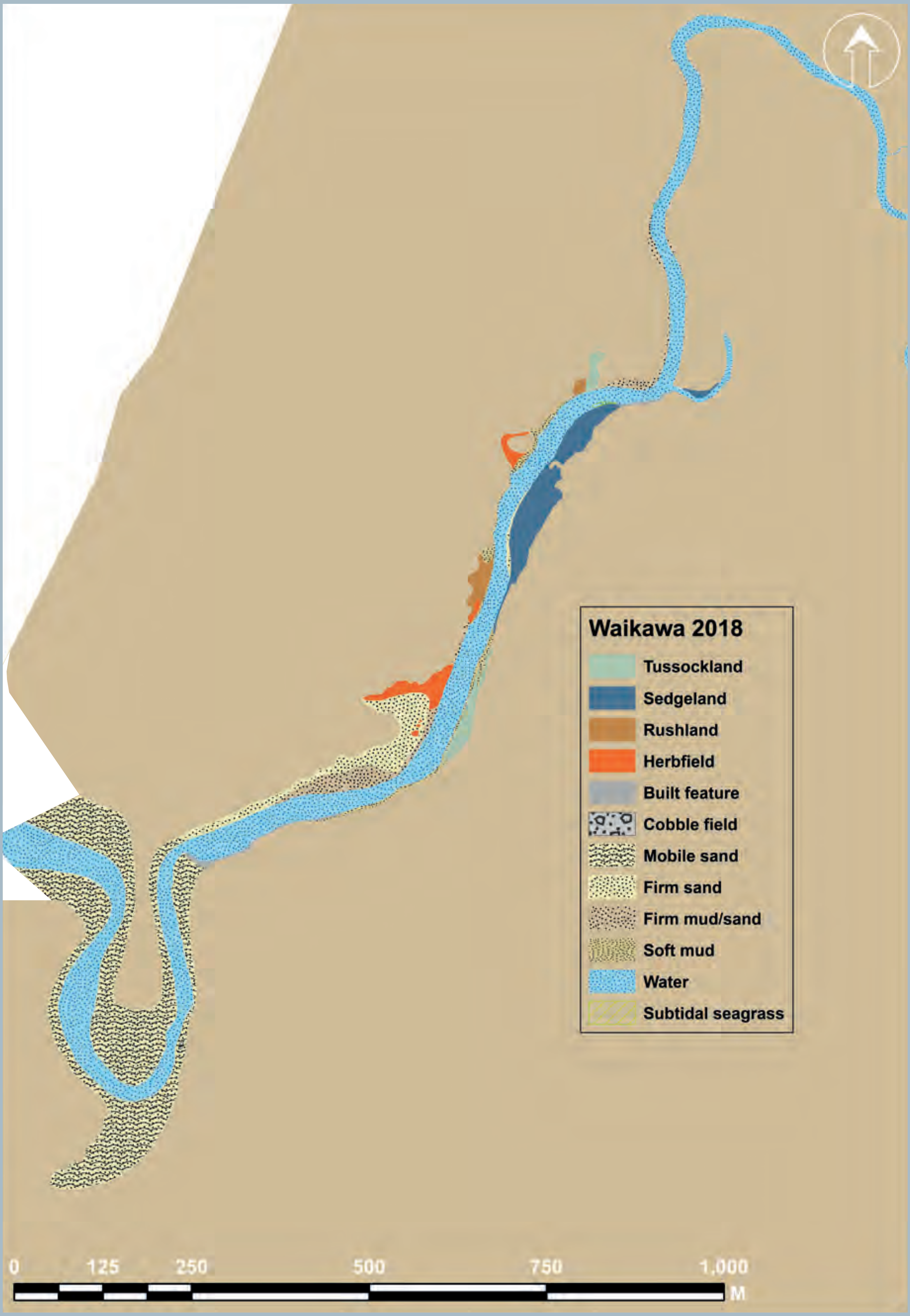


Figure 4. Overview of intertidal areas mapped - Waikawa Estuary, March 2018.

4. RESULTS AND DISCUSSION (CONTINUED)

4.1.2 INTERTIDAL EXTENT OF SOFT MUD


Firm muddy sand


Soft mud


Mobile sand

Where soil erosion from catchment disturbance exceeds the assimilative capacity of an estuary, adverse estuary impacts are expected from increased muddiness and turbidity, shallowing, increased nutrients, increased organic matter degradation by anoxic processes (e.g. sulphide production), increased contaminant concentrations (where fine muds provide a sink for catchment contaminants like heavy metals), and alterations to saltmarsh, seagrass, fish and invertebrate communities. In particular, multiple studies have shown estuarine macroinvertebrate communities to be adversely affected by mud accumulation, both through direct and indirect mechanisms including: declining sediment oxygenation, smothering, and compromisation of feeding habits (e.g. see Mannino and Montagna 1997; Rakocinski et al. 1997; Peeters et al. 2000; Norkko et al. 2002; Ellis et al. 2002; Thrush et al. 2003; Lohrer et al. 2004; Sakamaki and Nishimura 2009; Wehkamp and Fischer 2012; Robertson 2013; Robertson et al. 2015, 2016).

Because of such consequences, three key measures are commonly used to assess soft mud:

i. **Horizontal extent** (area of soft mud) - broad scale indicator (see rating in Table 2)

ii. **Vertical buildup** (sedimentation rate) - fine scale assessment using sediment plates (or retrospectively through historical coring). Ratings are currently under development as part of national ANZECC guidelines.

iii. **Sediment mud content** - fine scale indicator - recommended guideline is no increase from established baseline.

The area (horizontal extent) of intertidal soft mud is the primary sediment indicator used in the current broad scale report. Note that sediment plates, which enable future monitoring of vertical deposition/buildup in representative zones, have not yet been established in the estuary.

Figure 5 and Table 4 shows that soft or very soft muds covered 0.3 ha (4 %) of the intertidal area (excluding saltmarsh), a risk indicator rating of LOW. Soft muds were concentrated in small pockets of the middle and upper tidal reaches of the estuary channel where mud settlement is thought to predominantly reflect the presence of sheltered deposition zones and, to a lesser extent, salinity driven flocculation.

The 2018 soft mud extent (0.3 ha) was slightly higher than that reported in 2016 (0 ha, Robertson and Stevens 2016).

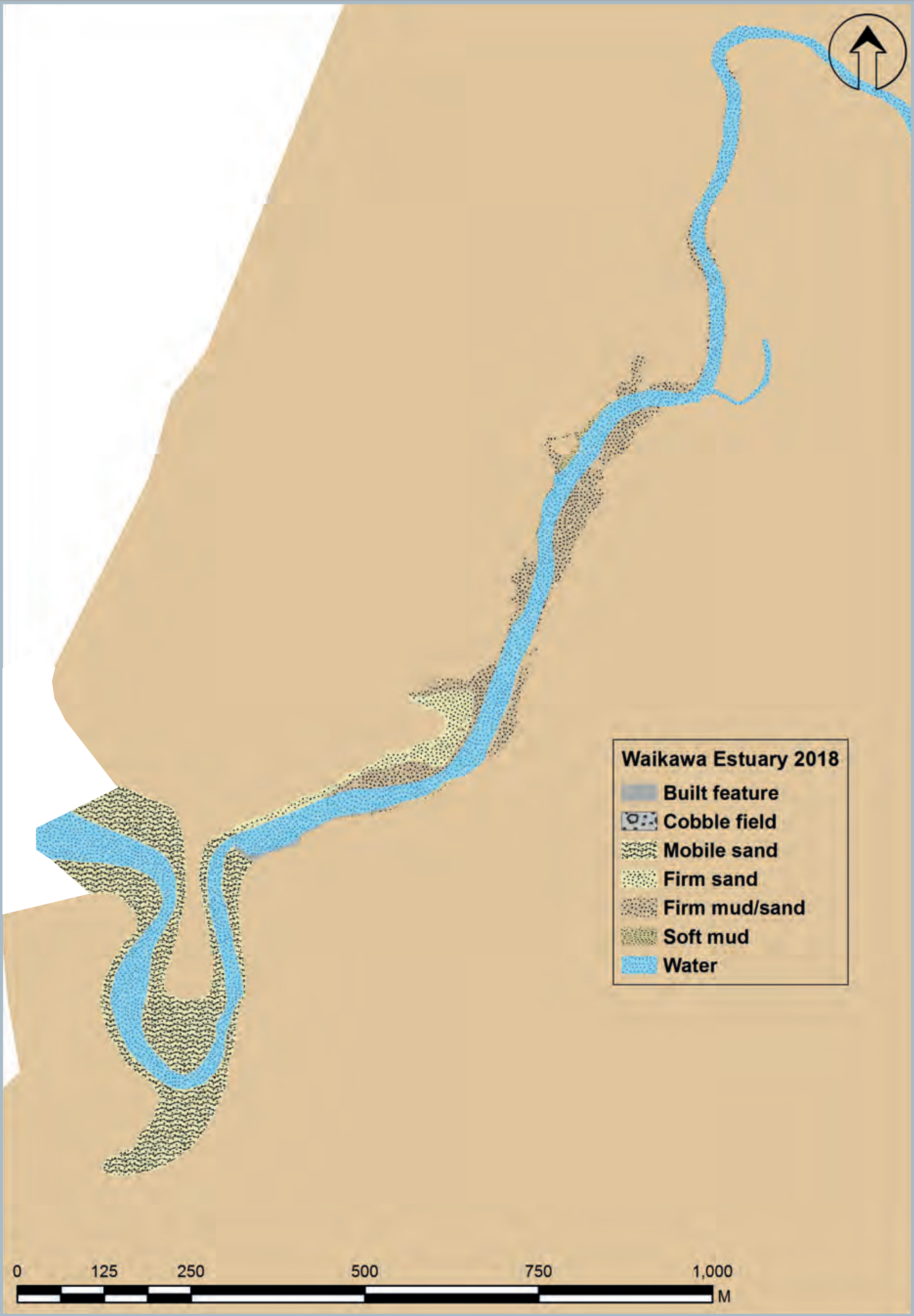


Figure 5. Map of dominant intertidal substrate types - Waikawa Estuary, March 2018.

4.1.3 INTERTIDAL SEDIMENT OXYGENATION

The primary indicators used to assess sediment oxygenation are aRPD depth and RP measured at 3 cm. These indicators were measured at representative sites throughout the dominant sand and mud substrate types. From these measurements, broad boundaries have been drawn of estuary zones where sediment oxygen is depleted to the extent that adverse impacts to macrofauna (sediment and surface dwelling animals) are expected. Because macrofauna are used as an indicator of ecological impacts to other taxa, it is expected that these zones will also be exerting adverse impacts on associated higher trophic communities including birds and fish.

All estuarine sediments appeared to be well oxygenated with the aRPD depth at >5 cm and the RP above -150 mV at 3 cm within sand and firm mud sand sediments that dominated cover in the estuary. Sediments were also well oxygenated in soft muds which covered 0.3 ha (4 %) of the total intertidal area. Together these results give an NZ ETI risk rating of VERY LOW. Sediment oxygenation was not recorded in 2016.

4.1.4 INTERTIDAL OPPORTUNISTIC MACROALGAE

Opportunistic macroalgae are a primary symptom of estuary eutrophication. They are highly effective at utilising excess nitrogen, enabling them to out-compete other seaweed species and, at nuisance levels, can form mats on the estuary surface which adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and saltmarsh. Macroalgae that becomes detached can also accumulate and decay in subtidal areas and on shorelines causing oxygen depletion and nuisance odours and conditions. The greater the density, persistence, and extent of macroalgal entrainment within sediments, the greater the subsequent impacts.

If the estuary supports <5 % opportunistic macroalgal cover within the Available Intertidal Habitat (AIH), overall quality status is reported as HIGH with no further sampling required. If there is >5 % cover, opportunistic macroalgal growth is assessed by mapping the spatial spread and density in the AIH, and calculating an OMBT "Ecological Quality Rating" (EQR) (WFD UKTAG, 2014).

Intertidal macroalgae was absent from Waikawa Estuary in March 2018 (see representative unvegetated habitat in below photos), with macroalgae quality status as HIGH, and the risk rating VERY LOW. Opportunistic macroalgae were present in the estuary in 2016 (i.e. as several moderate density (50-80 % cover), free-floating growths of *Ulva intestinalis* in shallow margin areas). The general low incidence of free-floating macroalgae in the estuary in 2018 was likely related to light limitation (from phytoplankton blooms - further investigated in Section 4.2 below) and/or flushing during recent flood periods (i.e. Waikawa River was in a moderate flow cycle (peak flow 2.7 m^3 s^{-1}) for previous 7 days; HRC's river flow database).


Middle Estuary, March 2018


Middle Estuary, February 2016

4.1.5 INTERTIDAL SALTMARSH

Sedgeland (three-square) bordering the main channel in the middle estuary

Herbfield (native celery and slender clubrush) in the lower estuary

Saltmarsh (vegetation able to tolerate saline conditions where terrestrial plants are unable to survive) is important as it is highly productive, naturally filters and assimilates sediment and nutrients, acts as a buffer that protects against introduced grasses and weeds, and provides an important habitat for a variety of species including fish and birds. Saltmarsh generally has the most dense cover in the sheltered and more strongly freshwater influenced upper estuary, and relatively sparse cover in the lower (more exposed and saltwater dominated) parts of the estuary, with the lower extent of saltmarsh growth limited for most species to above the height of mean high water neap (MHWN).

The primary measure to assess saltmarsh condition is the percent cover of the intertidal area. Table 5 and Figure 6 summarise the March 2018 results and show saltmarsh was present across 1.6 ha (19.4 %) of the intertidal estuary area, a risk indicator rating of LOW. Saltmarsh was dominated by sedgeland (57 %), predominantly three-square mixed with searush, in the middle estuary (see upper sidebar photo). Herbfields were also present (31 %) dominated by primrose and remuremu, commonly mixed with glasswort, native celery and slender clubrush, located in beds in lower and middle estuary regions (Figure 7, lower sidebar photo). There were smaller sized areas of rushland (12 %), comprising mainly searush, in the middle estuary.

Supporting measures also used are percent saltmarsh remaining compared to estimated natural state cover, and loss compared to an established baseline. While modification and loss of estuary saltmarsh and a densely vegetated buffer zone have likely been historically significant, because mapping the historical extent of the estuary was beyond the scope of the current work, it was not possible to estimate saltmarsh loss from the estuary or an associated risk rating.

Table 5. Summary of dominant saltmarsh cover, Waikawa Estuary, 2018.

Class	Dominant Species	Primary subdominant species	Area (ha)	Percentage
Rushland			0.2	**12 %**
	Juncus kraussii (Searush)	*Schoenoplectus pungens* (Three-square)	0.1	
	Juncus kraussii (Searush)	*Festuca arundinacea* (Tall fescue)	0.03	
Herbfield			0.5	**31 %**
	Samolus repens (Primrose)	*Selliera radicans* (Remuremu)	0.3	
	Selliera radicans (Remuremu)	*Samolus repens* (Primrose)	0.1	
Sedgeland			0.9	**57 %**
	Schoenoplectus pungens (Three-square)		0.1	
	Schoenoplectus pungens (Three-square)	*Juncus kraussii* (Searush)	0.8	
		Total	**1.6**	**100**

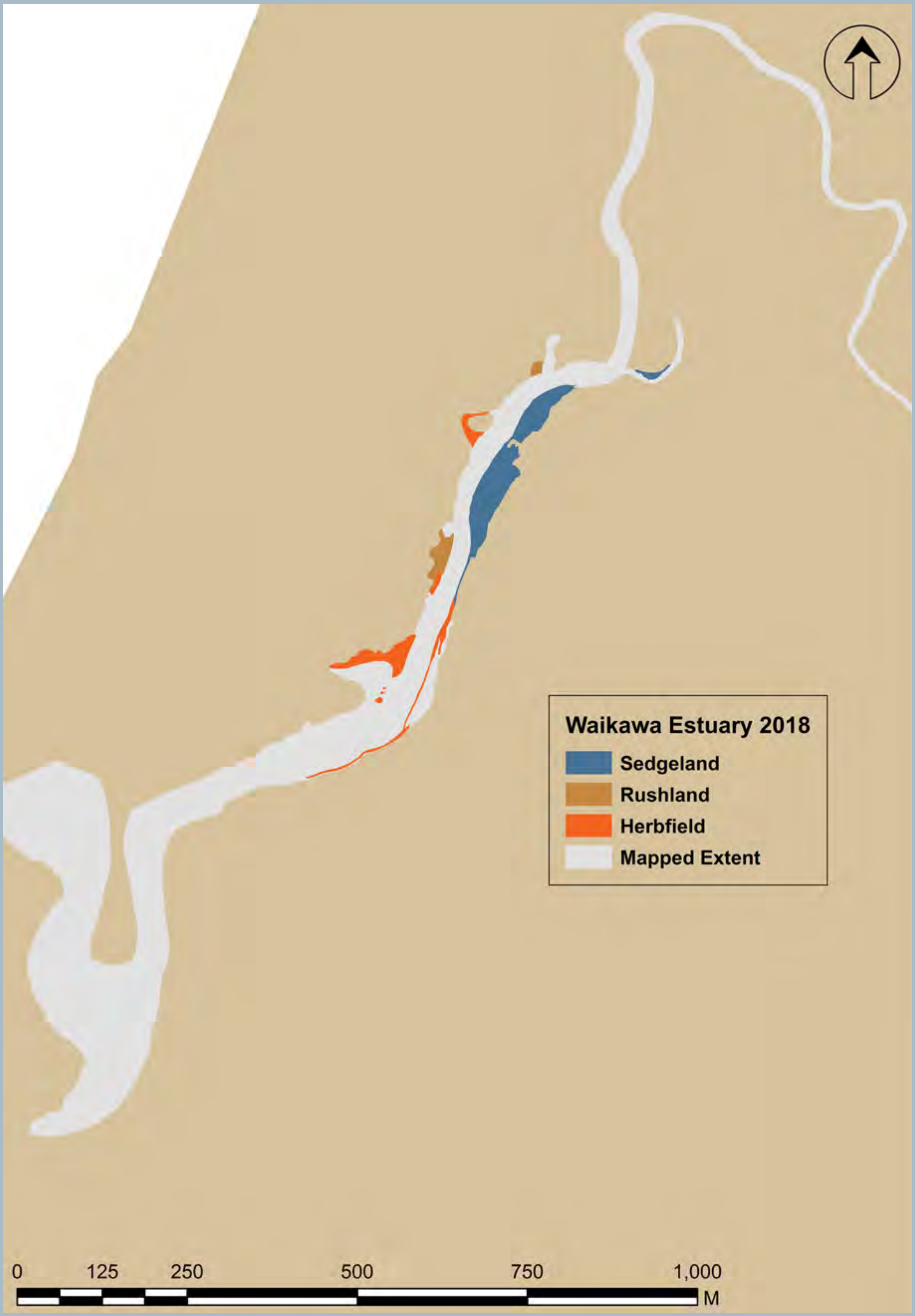


Figure 6. Map of dominant saltmarsh cover - Waikawa Estuary, March 2018.

4.2 ESTUARY SUBTIDAL CHANNEL CONDITION

BACKGROUND

In shallow tidal river type estuaries the rapid flushing time (<3 days for these estuaries) means water column phytoplankton cannot reach high concentrations before they are flushed to the sea. However, the Waikawa can experience elevated concentrations in parts of the main estuary channel during low flow-baseflow periods when inflowing freshwater flows over more saline tidal water and results in a dense isolated layer of saline bottom water that neither freshwater or tidal inflow currents are strong enough to flush out. Such isolated (or stratified) bottom water (often situated in the 1-2 m depth range) is susceptible to phytoplankton blooms, low dissolved oxygen, elevated nutrient concentrations and accumulation of fine sediment. In these situations, which vary between marine and close to freshwater salinities, a co-limiting situation between nitrogen (N) and phosphorus (P) is expected, and as a consequence any assessment of nutrient impacts should include both N and P.

Since both N and P are continually cycling between all of their major nutrient forms, an assessment of total N (TN), dissolved inorganic N (DIN) and total P (TP) is needed in order to gauge the level of N and P within an estuary and therefore its potential nutrient related health. Reliance on a single N or P fraction, e.g. inorganic N, results in inaccurate assessments, since even in a large algal bloom inorganic concentrations may be low due to the uptake by the plants (Howes et al. 2003). Based on the following literature, a TN, DIN and TP threshold concentration of approximately 0.4 mg TN l^{-1}, 0.096 mg DIN l^{-1} and 0.025 mg TP l^{-1} for the appearance of eutrophic conditions can be identified (see inset).

Literature supporting water column TN, DIN and TP thresholds

- In Horsen's Estuary, Denmark, research indicates a mean growing season threshold value of 0.398 mg TN l^{-1} to meet good ecological status (Hinsby et al. 2012). This research also identified a threshold for inorganic nutrients as 0.021 mg DIN l^{-1} and 0.007 mg DIP l^{-1}.
- Similarly, ECan Avon-Heathcote Estuary data from 2010-2014 suggests the appearance of eutrophic conditions may be unlikely below a TN concentration around 0.4 mg TN l^{-1} (John Zeldis pers. comm. 2016).
- In the US, EPA Region 1 has considered total N threshold concentrations for estuaries and coastal waters of 0.45 mg TN l^{-1} as protective of DO standards and 0.34 mg TN l^{-1} as protective for eelgrass (Latimer and Rego 2010, State of New Hampshire 2009, Benson et al. 2009).
- As concentrations at inner Massachusetts estuaries rose to levels above 0.40 g TN l^{-1}, with the entry of a wastewater nitrogen plume, eelgrass beds began declining and localized macroalgal accumulations were reported (Howes et al. 2003).
- In Waituna Lagoon, a coastal lagoon in Southland, thresholds of 0.33 mg N l^{-1} and 0.02 mg P l^{-1} have been identified to maintain a healthy rooted aquatic plant community (particularly key species like *Ruppia* spp.) (Robertson et al. 2013; Burns et al. 2000; Schallenburg et al. 2017).
- In Kakanui Estuary, a coastal lagoon in Otago, DIN thresholds of 0.07 mg DIN l^{-1} when the mouth is closed and 0.096 mg DIN l^{-1} when open have been proposed to limit nuisance level production of the opportunistic macroalga *Ulva* sp. (Plew and Barr 2015).

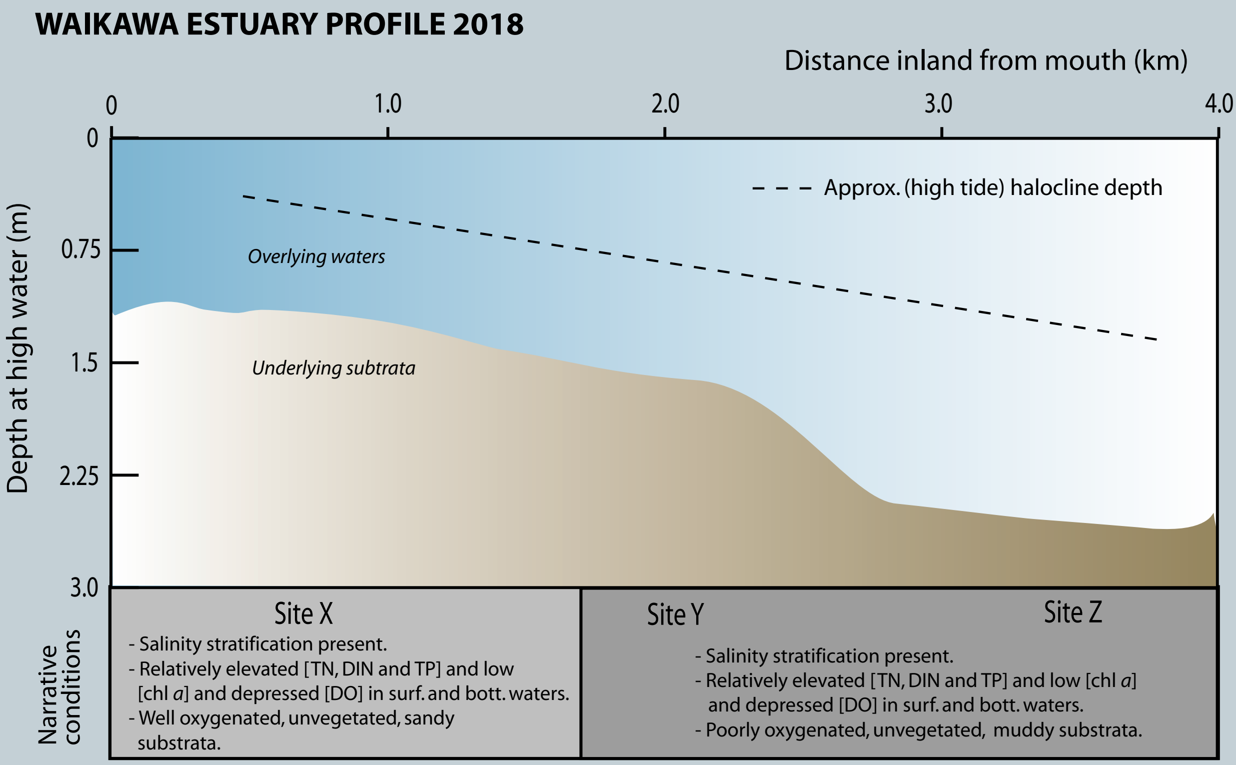
4. RESULTS AND DISCUSSION (CONTINUED)

A summary of the results of the 2017/18 synoptic subtidal channel monitoring of the Waikawa Estuary is presented in Table 6 and Figure 7, with detailed results in Appendix 6.

Table 6. Summary of fine scale water quality and bottom sediment results, Waikawa Estuary, 6 March 2018.

	Waikawa Site X		Waikawa Site Y		Waikawa Site Z	
Water Column	Bottom	Surface	Bottom	Surface	Bottom	Surface
Depth (m)	1.0	0.2	1.3	0.2	2.3	0.2
Temperature (degrees C)	22.0	22.0	23.1	21.6	21.9	20.2
Salinity (ppt)	18.3	9.9	30.7	5.9	28.2	2.7
Dissolved Oxygen (mg l^{-1})	7.0	6.5	7.0	6.5	5.3	6.2
Chlorophyll *a* (ug l^{-1})	2.4	1.6	6.0	1.3	3.9	1.3
Total N (g m^{-3})	0.2	0.9	0.3	0.9	0.8	1.0
Total Ammoniacal-N (g m^{-3})	0.01	0.10	0.01	0.10	0.08	0.07
Nitrate-N (g m^{-3})	0.1	0.6	0.1	0.6	0.1	0.7
Dissolved Reactive P (g m^{-3})	0.01	0.02	0.01	0.02	0.04	0.02
Total P (g m^{-3})	0.03	0.05	0.08	0.04	0.23	0.04

Bottom Sediment	aRPD (cm)	TOC (%)	Mud (%)	Sand (%)	Gravel (%)	TP (mg/kg)	TN (mg/kg)
Waikawa Site X	>3	0.1	1.6	98.4	<0.1	280	<500
Waikawa Site Y	1	3.0	68.4	29.6	2.0	760	2100
Waikawa Site Z	1	1.1	37.1	62.9	<0.1	440	700



Site X

- Salinity stratification present.
- Relatively elevated [TN, DIN and TP] and low [chl *a*] and depressed [DO] in surf. and bott. waters.
- Well oxygenated, unvegetated, sandy substrata.

Site Y Site Z

- Salinity stratification present.
- Relatively elevated [TN, DIN and TP] and low [chl *a*] and depressed [DO] in surf. and bott. waters.
- Poorly oxygenated, unvegetated, muddy substrata.

Figure 7. Generalised longitudinal profile (sea to river) of water column and underlying substrata characteristics at three estuary channel locations, Waikawa Estuary, 6 March 2018.

Middle estuary channel waters showing low phytoplankton (chlorophyll *a*) levels in 2018 (left) versus the presence of phytoplankton (cryptomonad) blooms in 2016 (right), Waikawa Estuary.

Sand-dominated, well oxygenated sediments at lower estuary channel Site X (left) compared to muddy, poorly oxygenated, nutrient rich sediments underlying the bottom waters at middle estuary Site Y (right), Waikawa Estuary, 2018.

RESULTS

The key findings from the water quality results for the surface and bottom waters at three estuary sites in the Waikawa Estuary (Sites X, Y and Z respectively - see Figure 1 for site locations) were as follows:

Water column stratification

There was minimal difference between surface and bottom water temperature, but salinity data (Figure 8) indicated salinity stratification was occurring at all three sites, but was most pronounced at mid and upper Sites Y and Z when sampled on 6 March 2018. The presence of water column stratification, and the potential for poorly flushed bottom water, means there is a risk of intermittent eutrophication of the estuary water column as investigated on the following pages.

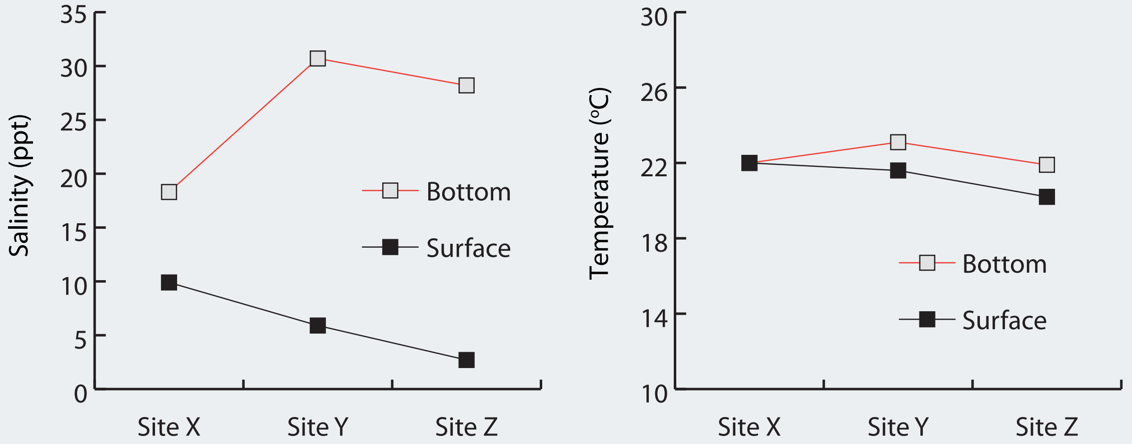


Figure 8. Salinity and temperature in surface and bottom water (*n* = 1) at three main channel sites, Waikawa Estuary, 2018.

Susceptibility to eutrophication based on water column TN, DIN, TP, chlorophyll a and dissolved oxygen concentrations

Total nitrogen (TN), dissolved inorganic nitrogen (DIN) and total phosphorus (TP) concentrations in both the surface and bottom waters at all three sites exceeded the eutrophication threshold levels of 0.4 mg TN l^{-1} and 0.096 mg DIN l^{-1}, and 0.025 mg P l^{-1} for all samples except TN in bottom waters at lower and mid estuary Sites X and Y (Figure 9 overleaf). These plots show that bottom water TP concentrations increased with distance inland from the mouth and was particularly elevated at upper estuary Site Z, but otherwise nutrient concentrations were relatively similar across sites.

Despite the above threshold TN, DIN and TP concentrations in surface and bottom waters, and the presence of phytoplankton blooms (i.e. coffee-coloured cryptomonads) in the sluggish bottom waters of the middle and upper estuary in 2016, chlorophyll *a* concentrations were low* in these same waters across all three sites (<10 µg l^{-1}) (Figure 10, top photo panel on previous page for visual comparison between 2016 and 2018). The likely explanation for this difference is that on the day of sampling in 2018 the water and associated nutrients and phytoplankton were being flushed from the estuary at such a rate that phytoplankton production (i.e. chlorophyll *a*) was limited to the low levels measured. Dissolved oxygen was at relatively normal levels (i.e. no pronounced depression or supersaturation) (Figure 10). Taken together, these results indicate a low expression of water column eutrophication symptoms (e.g. high chlorophyll *a* concentrations) on the day of sampling.

However, a note of caution is required when extrapolating data for one discrete sampling event (i.e. the 2018 results) into the likely situation for other times of the year. In particular, if the flow at the estuary mouth becomes constricted, high salinity bottom water could become trapped and result in ideal conditions for prolonged periods of bottom water eutrophication. To more accurately assess the susceptibility to eutrophication, it is recommended that monitoring be focused on prolonged low-flow conditions during this period and include an identical sampling protocol to that used in this report. Ideally, this would comprise a 3-year baseline and subsequent 5-yearly impact monitoring.

*** The NZ ETI threshold for chlorophyll *a* (the primary indicator of water column eutrophication) is expressed as the 90th percentile of monthly measures collected during the growing season, and for dissolved oxygen (the main eutrophication supporting indicator), a 7 day mean. Consequently the one-off measures collected on 6 March 2018 can only be used as an indication of current condition.**

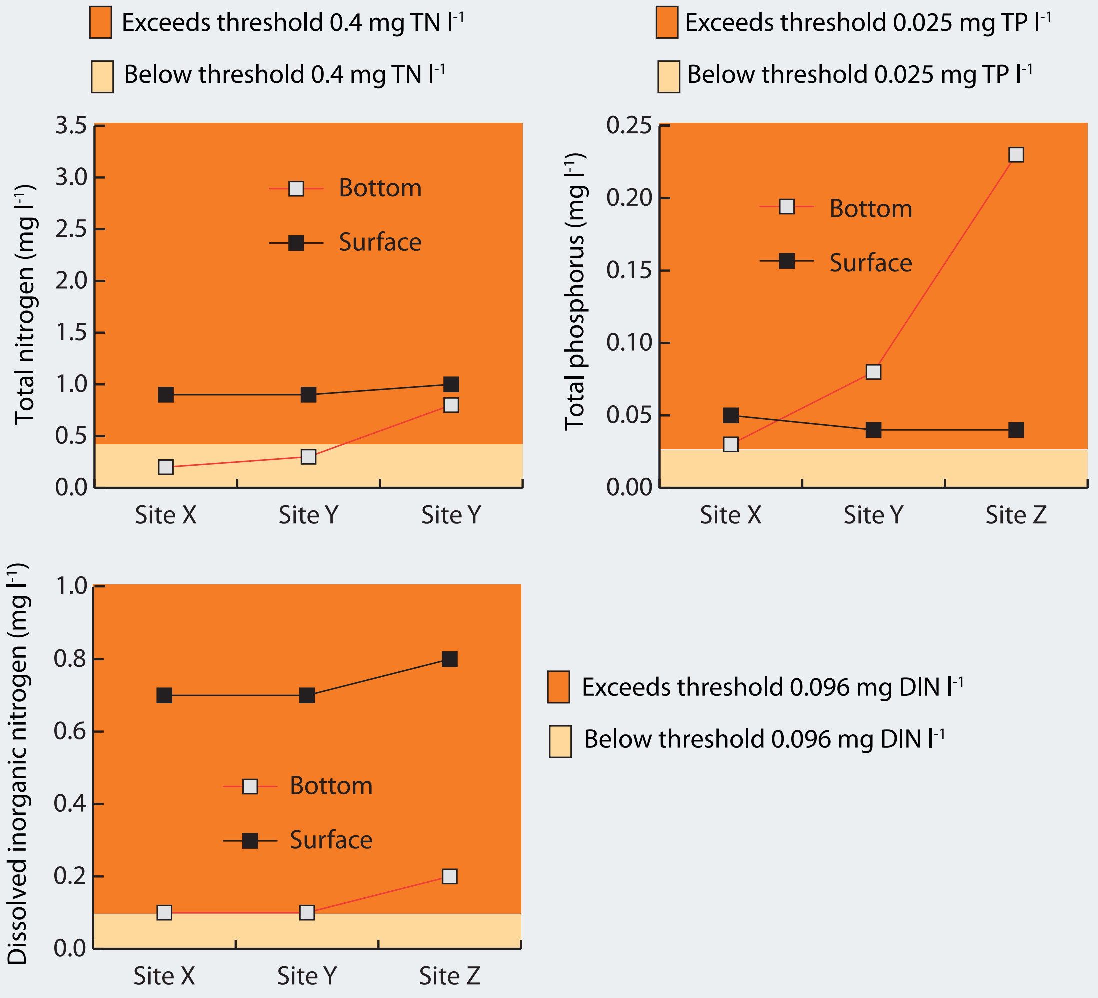


Figure 9. Total nitrogen, dissolved inorganic nitrogen and total phosphorus concentrations in surface and bottom water (*n* = 1) at three subtidal channel sites, Waikawa Estuary, March 2018.

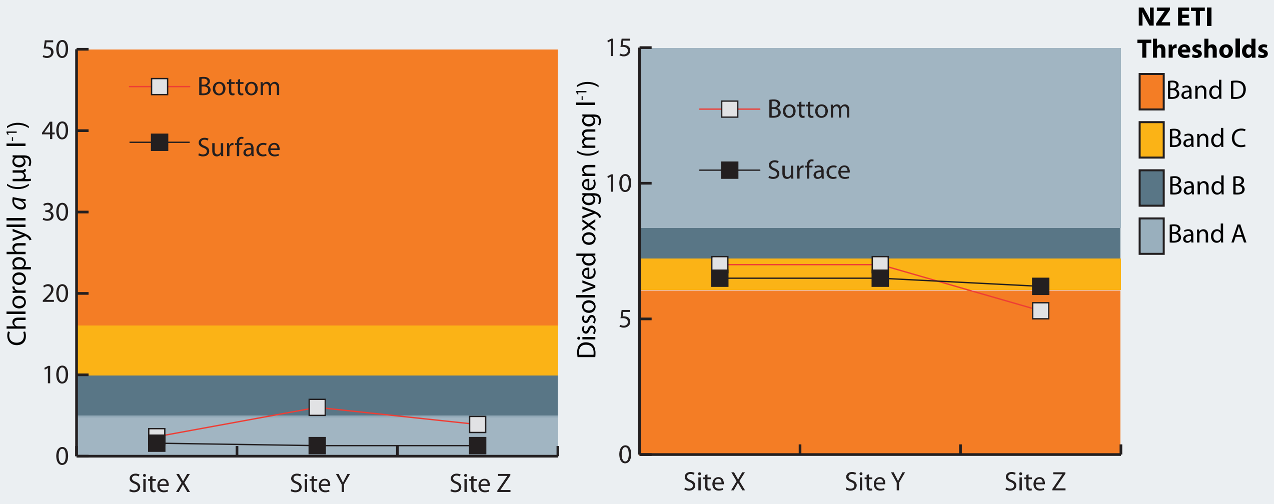


Figure 10. Chlorophyll *a* and dissolved oxygen concentrations in surface and bottom water (*n* = 1) at three subtidal channel sites, Waikawa Estuary, 2018.

4.3 NZ Estuary Trophic Index

In order to combine the results for all the indicators of eutrophication in the estuary and produce an overall eutrophication score, the NZ Estuary Trophic Index tool (NZ ETI) was used (Robertson et al. 2016a,b). This tool is designed to enable the consistent assessment of estuary state in relation to nutrient enrichment, and also includes assessment criteria for sediment muddiness issues. An integrated online calculator is available [https://shiny.niwa.co.nz/Estuaries-Screening-Tool-1/] to calculate estuary physical and nutrient load susceptibility (primarily based on catchment nutrient loads combined with mixing and dilution in the estuary), as well as trophic expression based on key estuary indicators [https://shiny.niwa.co.nz/Estuaries-Screening-Tool-2/]. The more indicators included, the more robust the ETI score becomes.

The indicators used to derive an ETI score and determine current trophic and sedimentation state for the Waikawa Estuary are presented in below (Table 7) using the 2018 synoptic monitoring results presented in this report.

ETI Tool 2 online calculator scores the estuary 0.85, Band D, a rating of “HIGH” for eutrophic symptoms. This is driven primarily by the elevated phytoplankton biomass (chl *a* - measured monthly over the 2017/18 (Nov-March) summer period by HRC staff) in the estuary.

Table 7. Primary and supporting indicator values used to calculate an ETI score for Waikawa Estuary, 6 March 2018.

ETI SCORING SUMMARY FOR WAIKAWA ESTUARY, 2018.			**NIWA online calculator**
PRIMARY SYMPTOM INDICATORS FOR SHALLOW SHORT RESIDENCE TIME RIVER ESTUARIES (AT LEAST 1 PRIMARY SYMPTOM INDICATOR REQUIRED)			**Primary symptom value**
Required	Opportunistic Macroalgae	Macroalgal Ecological Quality - Opportunistic Macroalgal Blooming Tool (OMBT) coefficient	1
	Macroalgal Gross Nuisance Zone (GNA) %	% Gross Nuisance Area (GNA)/Estuary Area	0
	Macroalgal GNA Ha	Ha Gross Nuisance Area (GNA)	0
Optional	Phytoplankton biomass	Chl *a* (summer 90 pctl, mg m^{-3})	181*
	Cyanobacteria (if issue identified) - NOTE ETI rating not yet developed		-
SUPPORTING INDICATORS FOR SHALLOW SHORT RESIDENCE TIME RIVER ESTUARIES (MUST INCLUDE A MINIMUM OF 1 REQUIRED INDICATOR)			**Supporting Indicator Value**
Required indicators	Sediment Oxygenation	Mean Redox Potential (mV) at 1 cm depth in most impacted sediments and representing at least 10 % of estuary area	-266
		% of intertidal estuary with Redox Potential <-150 mV at 3 cm or aRPD <1 cm	-
		Ha of estuary with Redox Potential <-150 mV at 3 cm or aRPD <1 cm	-
	Sediment Total Organic Carbon	Mean TOC (%) measured at 0-2 cm depth in most impacted sediments and representing at least 10 % of estuary area	3.0**
	Sediment Total Nitrogen	Mean TN (mg kg^{-1}) measured at 0-2 cm depth in most impacted sediments and representing at least 10 % of estuary area	2100**
	Macroinvertebrates	Mean AMBI score measured at 0-15 cm depth in most impacted sediments and representing at least 10 % of estuary area	-
Optional	Muddy sediment	Proportion of intertidal estuary area with soft mud (>25 % mud content)	4.0
	Sedimentation rate	Ratio of Mean estimated annual Current State Sediment Load (CSSL) relative to mean annual Natural State Sediemnt Load (NSSL)	-
	Dissolved Oxygen	1 day instantaneous minimum of water column measured from representative areas of estuary water column (including likely worst case condtions) (mg m^{-3})	5.3
	NZ ETI Score		**0.85**

* Based on HRC data collected monthly in surface waters at a single representative site between 3/10/17 and 27/03/18.

** Based on levels in subtidal sediments at three main estuary channel sites measured on 6 March 2018.

5. SUMMARY AND CONCLUSIONS

Synoptic broad scale habitat mapping and fine scale subtidal channel monitoring undertaken in March 2018, combined with ecological risk indicator ratings in relation to the key estuary stressors (i.e. muddiness, eutrophication and habitat modification) have been used to assess overall estuary condition. The overall key findings were as follows:

Muddiness

Soft or very soft muds covered 0.3 ha (4 %) of the intertidal area (excluding saltmarsh), a risk indicator rating of LOW. Soft muds were concentrated in small pockets of the mid-upper tidal reaches of the estuary channel where mud settlement is thought to predominantly reflect the presence of sheltered deposition zones and, to a lesser extent, salinity driven flocculation. Sediments in the lower estuary and main channel habitat were in relatively good condition with limited accumulation of muds and generally good sediment oxygenation, but were in poorer condition (elevated muds and poorly oxygenated) at monitoring sites located in the mid-upper channel.

Eutrophication

The NZ ETI combines a range of broad and fine scale indicators to provide an overall assessment of eutrophic expression in the estuary, including primary productivity through macroalgal growth and phytoplankton, and supporting indicators of sediment muddiness, oxygenation, organic content, nutrients, macroinvertebrates, and the presence of gross eutrophic zones (a combined presence of dense macroalgal growth, muds and poor sediment oxygenation). The overall ETI score for the estuary (based on 6 March 2018 results coupled with HRC collected summer chlorophyll *a* data) was 0.85, a risk rating of HIGH for eutrophic symptoms.

Intertidal nuisance macroalgal growths were not evident and there were no gross eutrophic zones present in the estuary. In addition, while sampling did identify salinity stratification and above threshold nutrient concentrations throughout the main estuary channel, there was no evidence of primary eutrophication symptoms (i.e. nuisance phytoplankton and/or macroalgal growths) in that part of the estuary. Taken together, these results indicate that on the day of sampling nutrient inputs to the estuary were most likely sufficiently flushed to the sea before they could cause eutrophication problems, as is typically the case for shallow tidal river type estuaries with mostly open mouths. However, the elevated chlorophyll *a* contents measured monthly in the main channel during the 2017/18 (Nov-March) summer indicates primary eutrophication symptoms can characterise that part of the estuary at particular times of the growing season, potentially exacerbated by periodic mouth closure/constriction.

Habitat modification

While not specifically assessed in this report, there has likely been significant historical modification of the estuary margin (particularly in the upper reaches) primarily through drainage, reclamation and conversion to pasture, greatly altering the ecological composition of the estuary and reduced the natural ecological connectivity between the estuary and surrounding natural habitats. In 2018, saltmarsh characterised 1.6 ha (19.4 %) of the intertidal area, comprised of herbfields (31 %) located in beds in lower and middle estuary zones, as well as rushland (12 %) and sedgeland (57 %) both largely constricted to the middle estuary. The associated risk indicator (remaining saltmarsh extent) was rated LOW. With only a small patch of subtidal seagrass present in the middle reaches, the estuary supported no intertidal seagrass beds in 2018.

In overview, the combined 2018 results place the estuary in a MODERATE state overall in relation to broad scale ecological features and subtidal channel water and sediment condition. Generalised comparisons between the 2016 synoptic survey and 2018 results show that 2016 results were similar to those from 2018, indicating overall ecological quality of the estuary has not changed significantly in the past two years.

6. MONITORING RECOMMENDATIONS

Waikawa Estuary has been identified by HRC as a priority for monitoring because it is an estuary with high ecological and human use values that is situated in a developed catchment, and therefore vulnerable to excessive sedimentation and eutrophication. As a consequence, it is a key part of HRC's coastal monitoring programme being undertaken throughout the Manawatu-Wanganui region. The first screening-level (synoptic) assessment of intertidal and subtidal habitat state has now been undertaken (March 2018).

Given the previous presence of eutrophic symptoms in the main channel of the estuary (i.e. in February 2016 and summer 2017/18), to assess the presence of eutrophication (including both benthic and water column effects), it is recommended that monitoring (annually for the first three years to establish a baseline and thereafter at 5 yearly intervals) be focused on prolonged lowflow conditions during the growing season (November-April) and include an identical sampling protocol to that used in this report. This proposed schedule will also be useful in confirming that this moderate risk estuary has not changed its risk rating in coming years. The next synoptic survey of Waikawa Estuary is therefore recommended for 2019.

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APPENDIX 1. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS.

Vegetation was classified using an interpretation of the Atkinson (1985) system, whereby dominant plant species were coded by using the two first letters of their Latin genus and species names e.g. marram grass, *Ammophila arenaria*, was coded as Amar. An indication of dominance is provided by the use of ( ) to distinguish subdominant species e.g. Amar(Caed) indicates that marram grass was dominant over ice plant (*Carpobrotus edulis*). The use of ( ) is not always based on percentage cover, but the subjective observation of which vegetation is the dominant or subdominant species within the patch. A measure of vegetation height can be derived from its structural class (e.g. rushland, scrub, forest).

Forest: Woody vegetation in which the cover of trees and shrubs in the canopy is >80% and in which tree cover exceeds that of shrubs. Trees are woody plants ≥10 cm diameter at breast height (dbh). Tree ferns ≥10cm dbh are treated as trees. Commonly sub-grouped into native, exotic or mixed forest.

Treeland: Cover of trees in the canopy is 20-80%. Trees are woody plants >10cm dbh. Commonly sub-grouped into native, exotic or mixed treeland.

Scrub: Cover of shrubs and trees in the canopy is >80% and in which shrub cover exceeds that of trees (c.f. FOREST). Shrubs are woody plants <10 cm dbh. Commonly sub-grouped into native, exotic or mixed scrub.

Shrubland: Cover of shrubs in the canopy is 20-80%. Shrubs are woody plants <10 cm dbh. Commonly sub-grouped into native, exotic or mixed shrubland.

Tussockland: Vegetation in which the cover of tussock in the canopy is 20-100% and in which the tussock cover exceeds that of any other growth form or bare ground. Tussock includes all grasses, sedges, rushes, and other herbaceous plants with linear leaves (or linear non-woody stems) that are densely clumped and >100 cm height. Examples of the growth form occur in all species of *Cortaderia, Gahnia,* and *Phormium*, and in some species of *Chionochloa, Poa, Festuca, Rytidosperma, Cyperus, Carex, Uncinia, Juncus, Astelia, Aciphylla,* and *Celmisia*.

Duneland: Vegetated sand dunes in which the cover of vegetation in the canopy (commonly Spinifex, Pingao or Marram grass) is 20-100% and in which the vegetation cover exceeds that of any other growth form or bare ground.

Grassland: Vegetation in which the cover of grass (excluding tussock-grasses) in the canopy is 20-100%, and in which the grass cover exceeds that of any other growth form or bare ground.

Sedgeland: Vegetation in which the cover of sedges (excluding tussock-sedges and reed-forming sedges) in the canopy is 20-100% and in which the sedge cover exceeds that of any other growth form or bare ground. "Sedges have edges." Sedges vary from grass by feeling the stem. If the stem is flat or rounded, it's probably a grass or a reed, if the stem is clearly triangular, it's a sedge. Sedges include many species of *Carex, Uncinia,* and *Scirpus*.

Rushland: Vegetation in which the cover of rushes (excluding tussock-rushes) in the canopy is 20-100% and where rush cover exceeds that of any other growth form or bare ground. A tall grasslike, often hollow-stemmed plant, included in rushland are some species of *Juncus* and all species of *Leptocarpus*.

Reedland: Vegetation in which the cover of reeds in the canopy is 20-100% and in which the reed cover exceeds that of any other growth form or open water. Reeds are herbaceous plants growing in standing or slowly-running water that have tall, slender, erect, unbranched leaves or culms that are either round and hollow – somewhat like a soda straw, or have a very spongy pith. Unlike grasses or sedges, reed flowers will each bear six tiny petal-like structures. Examples include *Typha, Bolboschoenus, Scirpus lacutris, Eleocharis sphacelata,* and *Baumea articulata*.

Cushionfield: Vegetation in which the cover of cushion plants in the canopy is 20-100% and in which the cushion-plant cover exceeds that of any other growth form or bare ground. Cushion plants include herbaceous, semi-woody and woody plants with short densely packed branches and closely spaced leaves that together form dense hemispherical cushions.

Herbfield: Vegetation in which the cover of herbs in the canopy is 20-100% and where herb cover exceeds that of any other growth form or bare ground. Herbs include all herbaceous and low-growing semi-woody plants that are not separated as ferns, tussocks, grasses, sedges, rushes, reeds, cushion plants, mosses or lichens.

Lichenfield: Vegetation in which the cover of lichens in the canopy is 20-100% and where lichen cover exceeds that of any other growth form or bare ground.

Introduced weeds: Vegetation in which the cover of introduced weeds in the canopy is 20-100% and in which the weed cover exceeds that of any other growth form or bare ground.

Seagrass meadows: Seagrasses are the sole marine representatives of the Angiospermae. They all belong to the order Helobiae, in two families: Potamogetonaceae and Hydrocharitaceae. Although they may occasionally be exposed to the air, they are predominantly submerged, and their flowers are usually pollinated underwater. A notable feature of all seagrass plants is the extensive underground root/rhizome system which anchors them to their substrate. Seagrasses are commonly found in shallow coastal marine locations, salt-marshes and estuaries and is mapped separately to the substrates they overlie.

Macroalgal bed: Algae are relatively simple plants that live in freshwater or saltwater environments. In the marine environment, they are often called seaweeds. Although they contain cholorophyll, they differ from many other plants by their lack of vascular tissues (roots, stems, and leaves). Many familiar algae fall into three major divisions: Chlorophyta (green algae), Rhodophyta (red algae), and Phaeophyta (brown algae). Macroalgae are algae observable without using a microscope. Macroalgal density, biomass and entrainment are classified and mapped separately to the substrates they overlie.

Cliff: A steep face of land which exceeds the area covered by any one class of plant growth-form. Cliffs are named from the dominant substrate type when unvegetated or the leading plant species when plant cover is ≥1%.

Rock field: Land in which the area of residual rock exceeds the area covered by any one class of plant growth-form. They are named from the leading plant species when plant cover is ≥1%.

Boulder field: Land in which the area of unconsolidated boulders (>200mm diam.) exceeds the area covered by any one class of plant growth-form. Boulder fields are named from the leading plant species when plant cover is ≥1%.

Cobble field: Land in which the area of unconsolidated cobbles (20-200 mm diam.) exceeds the area covered by any one class of plant growth-form. Cobble fields are named from the leading plant species when plant cover is ≥1%.

Gravel field: Land in which the area of unconsolidated gravel (2-20 mm diameter) exceeds the area covered by any one class of plant growth-form. Gravel fields are named from the leading plant species when plant cover is ≥1%.

Mobile sand: Granular beach sand characterised by a rippled surface layer from strong tidal or wind-generated currents. Often forms bars and beaches.

Firm or soft sand: Sand flats may be mud-like in appearance but are granular when rubbed between the fingers and no conspicuous fines are evident when sediment is disturbed e.g. a mud content <1%. Classified as firm sand if an adult sinks <2 cm or soft sand if an adult sinks >2 cm.

Firm muddy sand: A sand/mud mixture dominated by sand with a moderate mud fraction (e.g. 1-10%), the mud fraction conspicuous only when sediment is mixed in water. The sediment appears brown, and may have a black anaerobic layer below. From a distance appears visually similar to firm sandy mud, firm or soft mud, and very soft mud. When walking you'll sink 0-2 cm. Granular when rubbed between the fingers.

Firm sandy mud: A sand/mud mixture dominated by sand with an elevated mud fraction (e.g. 10-25%), the mud fraction visually conspicuous when walking on it. The surface appears brown, and may have a black anaerobic layer below. From a distance appears visually similar to firm muddy sand, firm or soft mud, and very soft mud. When walking you'll sink 0-2 cm. Granular when rubbed between the fingers, but with a smoother consistency than firm muddy sand.

Firm or soft mud: A mixture of mud and sand where mud is a major component (e.g. >25% mud). Sediment rubbed between the fingers retains a granular component but is primarily smooth/silken. The surface appears grey or brown, and may have a black anaerobic layer below. From a distance appears visually similar to firm muddy sand, firm sandy mud, and very soft mud. Classified as firm mud if an adult sinks <5 cm (usually if sediments are dried out or another component e.g. gravel prevents sinking) or soft mud if an adult sinks >5 cm.

Very soft mud: A mixture of mud and sand where mud is the major component (e.g. >50% mud), the surface appears brown, and may have a black anaerobic layer below. When walking you'll sink >5 cm unless another component e.g. gravel prevents sinking. From a distance appears visually similar to firm muddy sand, firm sandy mud, and firm or soft mud. Sediment rubbed between the fingers may retain a slight granular component but is primarily smooth/silken.

Cockle bed /Mussel reef/ Oyster reef: Area that is dominated by both live and dead cockle shells, or one or more mussel or oyster species respectively.

Sabellid field: Area that is dominated by raised beds of sabellid polychaete tubes.

Shell bank: Area that is dominated by dead shells.

Artificial structures: Introduced natural or man-made materials that modify the environment. Includes rip-rap, rock walls, wharf piles, bridge supports, walkways, boat ramps, sand replenishment, groynes, flood control banks, stopgates.

APPENDIX 2. NOTES SUPPORTING RISK INDICATOR RATINGS (TABLE 2)

NOTES to Table 2: See Robertson et al. (2016a, 2016b) for further information supporting these ratings.

Soft Mud Percent Cover. Soft mud (>25% mud content) has been shown to result in a degraded macroinvertebrate community (Robertson et al. 2015, 2016), and excessive mud decreases water clarity, lowers biodiversity and affects aesthetics and access. Because estuaries are a sink for sediments, the presence of large areas of soft mud is likely to lead to major and detrimental ecological changes that could be very difficult to reverse. In particular, its presence indicates where changes in land management may be needed. If an estuary is suspected of being an outlier (e.g. has >25% mud content but substrate remains firm to walk on), it is recommended that the initial broad scale assessment be followed by particle grain size analyses of relevant areas to determine the extent of the estuary with sediment mud contents >25%.

Sedimentation Mud Content. Below mud contents of 20-30% sediments are relatively incohesive and firm to walk on. Above this, they become sticky and cohesive and are associated with a significant shift in the macroinvertebrate assemblage to a lower diversity community tolerant of muds. This is particularly pronounced if elevated mud contents are contiguous with elevated total organic carbon concentrations, which typically increase with mud content, as do the concentrations of sediment bound nutrients and heavy metals. Consequently, muddy sediments are often poorly oxygenated, nutrient rich, and on intertidal flats of estuaries can be overlain with dense opportunistic macroalgal blooms. High mud contents also contribute to poor water clarity through ready resuspension of fine muds, impacting on seagrass, birds, fish and aesthetic values.

apparent Redox Potential Discontinuity (aRPD). aRPD depth, the transition between oxygenated sediments near the surface and deeper anoxic sediments, is a primary estuary condition indicator as it is a direct measure of whether nutrient and organic enrichment exceeds levels causing nuisance (anoxic) conditions. Knowing if the aRPD is close to the surface is important for two main reasons:

1. As the aRPD layer gets close to the surface, a “tipping point” is reached where the pool of sediment nutrients (which can be large), suddenly becomes available to fuel algal blooms and to worsen sediment conditions.
2. Anoxic sediments contain toxic sulphides and support very little aquatic life.

In sandy porous sediments, the aRPD layer is usually relatively deep (>3cm) and is maintained primarily by current or wave action that pumps oxygenated water into the sediments. In finer silt/clay sediments, physical diffusion limits oxygen penetration to <1cm (Jørgensen and Revsbech 1985) unless bioturbation by infauna oxygenates the sediments. The tendency for sediments to become anoxic is much greater if the sediments are muddy.

Redox Potential (Eh). For meter approaches, Eh measurements represent a composite of multiple redox equilibria measured at the surface of a redox potential electrode coupled to a millivolt meter (Rosenberg et al. 2001) (often called an ORP meter) and reflects a system’s tendency to receive or donate electrons. The electrode is inserted to different depths into the sediment and the extent of reducing conditions at each depth recorded (RPD is the depth at which the redox potential is ~0mV, Fenchel and Riedl 1970, Revsbech et al. 1980, Birchenough et al. 2012, Hunting et al. 2012). The Eh rating bands reflect the presence of healthy macrofauna communities in sediments below the aRPD depth.

Opportunistic Macroalgae. The presence of opportunistic macroalgae is a primary indicator of estuary eutrophication, and when combined with gross eutrophic conditions (see previous) can cause significant adverse ecological impacts that are very difficult to reverse. Thresholds used to assess this indicator are derived from the OMBT (see Section 3 and Appendix 2), with results combined with those of other indicators to determine overall condition.

Seagrass. Seagrass (*Zostera muelleri*) grows in soft sediments in most NZ estuaries. It is widely acknowledged that the presence of healthy seagrass beds enhances estuary biodiversity and particularly improves benthic ecology (Nelson 2009). Though tolerant of a wide range of conditions, it is seldom found above mean sea level (MSL), and is vulnerable to fine sediments in the water column and sediment quality (particularly if there is a lack of oxygen and production of sulphide), rapid sediment deposition, excessive macroalgal growth, high nutrient concentrations, and reclamation. Decreases in seagrass extent is likely to indicate an increase in these types of pressures.

As a baseline measure of seagrass presence, a continuous index (the seagrass coefficient - SC) has been developed to rate seagrass condition based on the percentage cover of seagrass in defined categories using the following equation: SC=((0 x %seagrass cover <1%)+(0.5 x %cover 1-5%)+(2 x %cover 6-10%)+(3.5 x %cover 11-20%)+(6 x %cover 21-50%)+(9 x %cover 51-80%)+(12 x %cover >80%))/100. Because estuaries are likely to support variable natural seagrass extents, the SC rating is intended to highlight estuaries with low seagrass cover for further evaluation (i.e. estimate natural seagrass cover to determine current state), and to provide an estuary specific metric against which future change can be assessed. It is not intended that the SC be used to directly compare different estuaries. The “early warning trigger” for initiating management action is a trend of decreasing SC.

Saltmarsh. Saltmarshes have high biodiversity, are amongst the most productive habitats on earth, and have strong aesthetic appeal. They are sensitive to a wide range of pressures including land reclamation, margin development, flow regulation, sea level rise, grazing, wastewater contaminants, and weed invasion. Most NZ estuarine saltmarsh grows in the upper estuary margins above mean high water neap (MHWN) tide where vegetation stabilises fine sediment transported by tidal flows. Saltmarsh zonation is commonly evident, resulting from the combined influence of factors including salinity, inundation period, elevation, wave exposure, and sediment type. Highest saltmarsh diversity is generally present above mean high water spring (MHWS) tide where a variety of salt tolerant species grow including scrub, sedge, tussock, grass, reed, rush and herb fields. Between MHWS and MHWN, saltmarsh is commonly dominated by relatively low diversity rushland and herbfields. Below this, the MHWN to MSL range is commonly unvegetated or limited to either mangroves or *Spartina*, the latter being able to grow to MLWN. Further work is required to develop a comprehensive saltmarsh metric for NZ. As an interim measure, the % of the intertidal area comprising saltmarsh is used to indicate saltmarsh condition. Two supporting metrics are also proposed: i. % loss from Estimated Natural State Cover. This assumes that a reduction in natural state saltmarsh cover corresponds to a reduction in ecological services and habitat values. ii. % of available habitat supporting saltmarsh. This assumes that saltmarsh should be growing throughout the majority of the available saltmarsh habitat (tidal area above MHWN), and that where this does not occur, ecological services and habitat values are reduced. The interim risk ratings proposed for these ratings are Very Low=>80-100%, Low=>60-80%, Moderate=>40-60%, and High=<40%. The “early warning trigger” for initiating management action/further investigation is a trend of a decreasing saltmarsh area or saltmarsh growing over <80% of the available habitat.

Vegetated Margin. The presence of a terrestrial margin dominated by a dense assemblage of scrub/shrub and forest vegetation acts as an important buffer between developed areas and the saltmarsh and estuary. This buffer is sensitive to a wide range of pressures including land reclamation, margin development, flow regulation, sea level rise, grazing, wastewater contaminants, and weed invasion. It protects the estuary against introduced weeds and grasses, naturally filters sediments and nutrients, and provides valuable ecological habitat. Reduction in the vegetated terrestrial buffer around the estuary is likely to result in a decline in estuary quality. The “early warning trigger” for initiating management action is <50% of the estuary with a densely vegetated margin.

Change from Baseline Condition. Where natural state conditions for high value habitat of seagrass, saltmarsh, and densely vegetated terrestrial margin are unknown it is proposed that % change from the first measured baseline condition be used to determine trends in estuary condition. It is assumed that increases in such habitat are desirable (i.e. represent a Very Low risk rating), and decreases are undesirable. For decreases, the interim risk ratings proposed are: Very Low=<5%, Low=>5-10%, Moderate=>10-20%, and High=>20%. For indicators of degraded habitat e.g. extent of soft mud or gross eutrophic conditions, the same interim risk rating bands are proposed, but are applied to increases in extent.

APPENDIX 3. NOTES ON SAMPLING, RESOLUTION AND ACCURACY

Sediment sampling and analysis

At selected sampling sites redox potential (RP) was measured with an oxidation-reduction potential meter at 0, 1, 3, 6 and 10 cm depths below the substrate surface, and the aRPD depth and substrate type recorded. These results have been used to generate broad scale maps showing areas where sediment oxygenation is depleted to the extent that adverse impacts to macrofauna (sediment and surface dwelling animals) are expected i.e. where RPD at 3cm <-150mV or aRPD <1cm (Robertson et al. 2016b).

Sampling resolution and accuracy

Estimates of error for different measurements have been made based on the field data collected to date. Initial broad scale mapping is intended to provide a rapid overview of estuary condition based on the mapping of features visible on aerial photographs, supported by ground-truthing to validate the visible features. The accuracy of mapping is therefore primarily determined by the resolution of the available photos, and secondarily by the extent of groundtruthing. In most instances features with readily defined edges such as saltmarsh beds, rockfields etc. can be accurately mapped to within 1-2m of their boundaries. The largest area for potential error is where boundaries are not readily visible on photographs e.g. where firm muddy sands transition to soft muds. These boundaries require field validation. Extensive mapping experience has shown that it is possible to define such boundaries to within ±10m where they have been thoroughly ground-truthed using NEMP classifications. Because broad scale mapping necessitates the grouping of variable and non-uniform patches (which introduces a certain amount of variation) overall broad scale accuracy is unlikely to exceed ±10% for boundaries not readily visible on photographs.

Where initial broad scale mapping results indicate a need for greater resolution of boundaries (e.g. to increase certainty about the extent of soft mud areas), or to define changes within NEMP categories (e.g. to define the mud content within firm muddy sand habitat), then issue-specific approaches are recommended. The former includes more widespread ground-truthing, and the latter uses transect or grid based grain size sampling.

For specific broad scale seagrass and macroalgae features that are spatially and temporally variable, the overall spatial extent, and boundaries between different percentage cover and density areas, are considered accurate to within ±10m where they have been thoroughly ground-truthed using NEMP classifications. Accuracy declines when assessed remotely e.g. from aerial photographs, and particularly so when assessing lower density (<50%) cover which is commonly not visible on aerial coverages. As previously, the most accurate measures are obtained with increasing field time (and cost).

Within mapped boundaries, broad scale estimates of percentage cover and density, due to the grouping of variable and non-uniform patches, are considered accurate to ±10%. These however can be assessed to a much higher degree of accuracy using fine scale quadrat based approaches such as the OMBT which can also be increased by applying fine scale approaches estuary-wide if a very high degree of accuracy is considered important.

For the OMBT, a methodology for calculating a measure of the confidence of class (CofC), has been developed (Davey, 2009) that defines the specific accuracy of the measures undertaken. Called CAPTAIN ('Confidence And Precision Tool Aids aNalysis') it calculates CofC at three levels: i. metric, ii. survey (single sampling event), and iii. water body over the reporting period (potentially several surveys). The upper and lower 90% Confidence Intervals for the SE of the EQR are presented in this report.

APPENDIX 4. OPPORTUNISTIC MACROALGAL BLOOMING TOOL

The UK-WFD (Water Framework Directive) Opportunistic Macroalgal Blooming Tool (OMBT) (WFD-UKTAG 2014) is a comprehensive 5 part multimetric index approach suitable for characterising the different types of estuaries and related macroalgal issues found in NZ. The tool allows simple adjustment of underpinning threshold values to calibrate it to the observed relationships between macroalgal condition and the ecological response of different estuary types. It incorporates sediment entrained macroalgae, a key indicator of estuary degradation, and addresses limitations associated with percentage cover estimates that do not incorporate biomass e.g. where high cover but low biomass are not resulting in significantly degraded sediment conditions. It is supported by extensive studies of the macroalgal condition in relation to ecological responses in a wide range of estuaries.

The 5 part multimetric OMBT, modified for NZ estuary types, is fully described below. It is based on macroalgal growth within the Available Intertidal Habitat (AIH) - the estuary area between high and low water spring tide able to support opportunistic macroalgal growth. Suitable areas are considered to consist of ***mud, muddy sand, sandy mud, sand, stony mud and mussel beds***. Areas which are judged unsuitable for algal blooms e.g. channels and channel edges subject to constant scouring, need to be excluded from the AIH. The following measures are then taken:

1. Percentage cover of the available intertidal habitat (AIH).

The percent cover of opportunistic macroalgal within the AIH is assessed. While a range of methods are described, visual rating by experienced ecologists, with independent validation of results is a reliable and rapid method. All areas within the AIH with macroalgal cover >5% are mapped spatially.

2. Total extent of area covered by algal mats (affected area (AA)) or affected area as a percentage of the AIH (AA/AIH,%).

In large water bodies with proportionately small patches of macroalgal coverage, the rating for total area covered by macroalgae (Affected Area - AA) might indicate high or good status, while the total area covered could actually be quite substantial and could still affect the surrounding and underlying communities. In order to account for this, an additional metric established is the affected area as a percentage of the AIH (i.e. (AA/AIH)*100). This helps to scale the area of impact to the size of the water body. In the final assessment the lower of the two metrics (the AA or percentage AA/AIH) is used, i.e. whichever reflects the worst case scenario.

3. Biomass of AIH (g.m-2).

Assessment of the spatial extent of the algal bed alone will not indicate the level of risk to a water body. For example, a very thin (low biomass) layer covering over 75% of a shore might have little impact on underlying sediments and fauna. The influence of biomass is therefore incorporated. Biomass is calculated as a mean for (i) the whole of the AIH and (ii) for the Affected Areas. The potential use of maximum biomass was rejected, as it could falsely classify a water body by giving undue weighting to a small, localised blooming problem. Algae growing on the surface of the sediment are collected for biomass assessment, thoroughly rinsed to remove sediment and invertebrate fauna, hand squeezed until water stops running, and the wet weight of algae recorded. For quality assurance of the percentage cover estimates, two independent readings should be within +/- 5%. A photograph should be taken of every quadrat for inter-calibration and cross-checking of percent cover determination. Measures of biomass should be calculated to 1 decimal place of wet weight of sample. For both procedures the accuracy should be demonstrated with the use of quality assurance checks and procedures.

4. Biomass of AA (g.m-2).

Mean biomass of Affected Area (AA), with the AA defined as the total area with macroalgal cover >5 %.

5. Presence of Entrained Algae (percent of quadrats).

Algae are considered entrained in muddy sediment when they are found growing >3 cm deep within muddy sediments. The persistence of algae within sediments provides both a means for over-wintering of algal spores and a source of nutrients within the sediments. Buildup of weed within sediments therefore implies that blooms can become self-regenerating given the right conditions (Raffaelli et al. 1989). Absence of weed within the sediments lessens the likelihood of bloom persistence, while its presence gives greater opportunity for nutrient exchange with sediments. Consequently, the presence of opportunistic macroalgae growing within the surfacesediment was included in the tool.

All the metrics are equally weighted and combined within the multimetric, in order to best describe the changes in the nature and degree of opportunist macroalgae growth on sedimentary shores due to nutrient pressure.

Timing: Because the OMBT has been developed to classify data over the maximum growing season, sampling should target the peak bloom in summer (Dec-March), although peak timing may vary among water bodies, therefore local knowledge is required to identify the maximum growth period. Sampling is not recommended outside the summer period due to seasonal variations that could affect the outcome of the tool and possibly lead to misclassification; e.g. blooms may become disrupted by stormy autumn weather and often die back in winter. Sampling should be carried out during spring low tides in order to access the maximum area of the AIH.

APPENDIX 4. OPPORTUNISTIC MACROALGAL BLOOMING TOOL (CONTINUED)

Suitable Locations: The OMBT is suitable for use in estuaries and coastal waters which have intertidal areas of soft sedimentary substratum (i.e. areas of AIH for opportunistic macroalgal growth). The tool is not currently used for assessing ICOLLs due to the particular challenges in setting suitable reference conditions for these water bodies.

Derivation of Threshold Values.

Published and unpublished literature, along with expert opinion, was used to derive critical threshold values suitable for defining quality status classes (Table A2).

- **Reference Thresholds:** A UK Department of the Environment, Transport and the Regions (DETR) expert workshop suggested reference levels of <5% cover of AIH of climax and opportunistic species for high quality sites (DETR, 2001). In line with this approach, the WFD adopted <5% cover of opportunistic macroalgae in the AIH as equivalent to High status. From the WFD North East Atlantic intercalibration phase 1 results, German research into large sized water bodies revealed that areas over 50ha may often show signs of adverse effects, however if the overall area was less than 1/5th of this, adverse effects were not seen, so the High/Good boundary was set at 10ha. In all cases a reference of 0% cover for truly un-impacted areas was assumed. Note: opportunistic algae may occur even in pristine water bodies as part of the natural community functioning.

  The proposal of reference conditions for levels of biomass took a similar approach, considering existing guidelines and suggestions from DETR (2001), with a tentative reference level of <100g m-2 wet weight. This reference level was used for both the average biomass over the affected area and the average biomass over the AIH. As with area measurements a reference of zero was assumed. An ideal of no entrainment (i.e. no quadrats revealing entrained macroalgae) was assumed to be reference for un-impacted waters. After some empirical testing in a number of UK water bodies a High / Good boundary of 1% of quadrats was set.

- **Class Thresholds for Percent Cover**:

  High/Good boundary set at 5%. Based on the finding that a symptom of the potential start of eutrophication is when: (i) 25% of the available intertidal habitat has opportunistic macroalgae and (ii) at least 25% of the sediment (i.e. 25% in a quadrat) is covered (Comprehensive Studies Task Team (DETR, 2001)). This implies that an overall cover of the AIH of 6.25% (25*25%) represents the start of a potential problem.

  Good / Moderate boundary set at 15%. True problem areas often have a >60% cover within the affected area of 25% of the water body (Wither 2003). This equates to 15% overall cover of the AIH (i.e. 25% of the water body covered with algal mats at a density of 60%).

  Poor/Bad boundary is set at >75%. The Environment Agency has considered >75% cover as seriously affecting an area (Foden et al. 2010).

- **Class Thresholds for Biomass**. Class boundaries for biomass values were derived from DETR (2001) recommendations that <500 g.m-2 wet weight was an acceptable level above the reference level of <100 g.m-2 wet weight. In Good status only slight deviation from High status is permitted so 500 g.m-2 represents the Good/Moderate boundary. Moderate quality status requires moderate signs of distortion and significantly greater deviation from High status to be observed. The presence of >500 g.m-2 but less than 1,000 g.m-2 would lead to a classification of Moderate quality status at best, but would depend on the percentage of the AIH covered. >1kg.m-2 wet weight causes significant harmful effects on biota (DETR 2001, Lowthion et al. 1985, Hull 1987, Wither 2003).
- **Thresholds for entrained algae**. Empirical studies testing a number of scales were undertaken on a number of impacted waters. Seriously impacted waters have a very high percentage (>75%) of the beds showing entrainment (Poor / Bad boundary). Entrainment was felt to be an early warning sign of potential eutrophication problems so a tight High /Good standard of 1% was selected (this allows for the odd change in a quadrat or error to be taken into account). Consequently the Good / Moderate boundary was set at 5% where (assuming sufficient quadrats were taken) it would be clear that entrainment and potential over wintering of macroalgae had started.

Each metric in the OMBT has equal weighting and is combined to produce the ecological quality ratio score (EQR).

Table A2. The final face value thresholds and metrics for levels of ecological quality status in the UK-WFD 2014.

Quality Status	High	Good	Moderate	Poor	Bad
EQR (Ecological Quality Rating)	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
% cover on Available Intertidal Habitat (AIH)	0 - ≤5	>5 - ≤15	>15 -≤25	>25 - ≤75	>75 - 100
Affected Area (AA) of >5% macroalgae (ha)*	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass (g.m^2 wet weight) of AIH	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
Average biomass (g.m^2 wet weight) of AA	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
% algae >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

*N.B. Only the lower EQR of the 2 metrics, AA or AA/AIH is used in the final EQR calculation.

APPENDIX 4. OPPORTUNISTIC MACROALGAL BLOOMING TOOL (CONTINUED)

EQR Calculation

Each metric in the OMBT has equal weighting and is combined to produce the **Ecological Quality Ratio** score (EQR).

The face value metrics work on a sliding scale to enable an accurate metric EQR value to be calculated; an average of these values is then used to establish the final water body level EQR and classification status. The EQR determining the final water body classification ranges between a value of zero to one and is converted to a Quality Status by using the following categories:

Quality Status	High	Good	Moderate	Poor	Bad
EQR (Ecological Quality Rating)	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2

The EQR calculation process is as follows:

1. Calculation of the face value (e.g. percentage cover of AIH) for each metric. To calculate the individual metric face values:

- Percentage cover of AIH (%) = (Total % Cover / AIH} x 100 - where Total % cover = Sum of {(patch size) / 100} x average % cover for patch
- Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%).
- Biomass of AIH (g.m-2) = Total biomass / AIH - where Total biomass = Sum of (patch size x average biomass for the patch)
- Biomass of Affected Area (g.m-2) = Total biomass / AA - where Total biomass = Sum of (patch size x average biomass for the patch)
- Presence of Entrained Algae = (No. quadrats with entrained algae / total no. of quadrats) x 100
- Size of AA in relation to AIH (%) = (AA/AIH) x 100

2. Normalisation and rescaling to convert the face value to an equidistant index score (0-1 value) for each index (Table A3).

The face values are converted to an equidistant EQR scale to allow combination of the metrics. These steps have been mathematically combined in the following equation:

Final Equidistant Index score = Upper Equidistant range value – ({Face Value - Upper Face value range} * (Equidistant class range / Face Value Class Range)).

Table A3 gives the critical values at each class range required for the above equation. The first three numeric columns contain the face values (FV) for the range of the index in question, the last three numeric columns contain the values of the equidistant 0-1 scale and are the same for each index. The face value class range is derived by subtracting the upper face value of the range from the lower face value of the range.

Note: the table is "simplified" with rounded numbers for display purposes. The face values in each class band may have greater than (>) or less than (<) symbols associated with them, for calculation a value of <5 is given a value of 4.999'.

The final EQR score is calculated as the average of equidistant metric scores.

A spreadsheet calculator is available to download from the UK WFD website to undertake the calculation of EQR scores.

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APPENDIX 4. OPPORTUNISTIC MACROALGAL BLOOMING TOOL (CONTINUED)

Table A3. Values for the normalisation and re-scaling of face values to EQR metric.

METRIC	QUALITY STATUS	FACE VALUE RANGES			EQUIDISTANT CLASS RANGE VALUES		
		Lower face value range (measurements towards the "Bad" end of this class range)	Upper face value range (measurements towards the "High" end of this class range)	Face Value Class Range	Lower 0-1 Equidistant range value	Upper 0-1 Equidistant range value	Equidistant Class Range
% Cover of Available Intertidal Habitat (AIH)	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤25	>15	9.999	≥0.4	<0.6	0.2
	Poor	≤75	>25	49.999	≥0.2	<0.4	0.2
	Bad	100	>75	24.999	0	<0.2	0.2
Average Biomass of AIH ($g.m^{-2}$ wet weight)	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.999	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.999	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.999	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.999	0	<0.2	0.2
Average Biomass of Affected Area (AA) ($g.m^{-2}$ wet weight)	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.999	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.999	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.999	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.999	0	<0.2	0.2
Affected Area (Ha)*	High	≤10	0	100	≥0.8	1	0.2
	Good	≤50	>10	39.999	≥0.6	<0.8	0.2
	Moderate	≤100	>50	49.999	≥0.4	<0.6	0.2
	Poor	≤250	>100	149.999	≥0.2	<0.4	0.2
	Bad	≤6000	>250	5749.999	0	<0.2	0.2
AA/AIH (%)*	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤50	>15	34.999	≥0.4	<0.6	0.2
	Poor	≤75	>50	24.999	≥0.2	<0.4	0.2
	Bad	100	>75	27.999	0	<0.2	0.2
% Entrained Algae	High	≤1	0	1	≥0.0	1	0.2
	Good	≤5	>1	3.999	≥0.2	<0.0	0.2
	Moderate	≤20	>5	14.999	≥0.4	<0.2	0.2
	Poor	≤50	>20	29.999	≥0.6	<0.4	0.2
	Bad	100	>50	49.999	1	<0.6	0.2

***N.B. Only the lower EQR of the metrics, AA or AA/AIH should be used in the final EQR calculation.**

Table A4. The final face value thresholds and metrics for levels of ecological quality status used to rate opportunistic macroalgae in the current study (modified from UK-WFD 2014).

Quality Status	High	Good	Moderate	Poor	Bad
EQR (Ecological Quality Rating)	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
% cover on Available Intertidal Habitat (AIH)	0 - ≤5	>5 - ≤15	>15 -≤25	>25 - ≤75	>75 - 100
Affected Area (AA) of >5% macroalgae (ha)*	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass ($g.m^2$ wet weight) of AIH	≥0 - 100	≥100 -200	≥200 - 500	≥500 - 1450	≥1450
Average biomass ($g.m^2$ wet weight) of AA	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
% algae >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

***Only the lower EQR of the 2 metrics, AA or AA/AIH is used in the final EQR calculation.**

APPENDIX 5. DETAILS ON ANALYTICAL METHODS

Sediment Indicator	Laboratory	Method	Detection Limit
Grain Size	R.J Hill	Wet sieving, gravimetric (calculation by difference).	0.1 g 100^{-g} dry wgt
Total Organic Carbon	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	0.05g 100^{-g} dry wgt
Total recoverable phosphorus	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	40 mg kg^{-1} dry wgt
Total nitrogen	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	500 mg kg^{-1} dry wgt
Dry Matter (Env)	R.J. Hill	Dried at 103 °C (removes 3-5 % more water than air dry)	

Water Quality Indicator	Laboratory	Method	Detection Limit
Filtration, Unpreserved	R.J Hill	Sample filtration through 0.45 µm membrane filter.	-
Total Kjeldahl Digestion	R.J Hill	Sulphuric acid digestion with copper sulphate catalyst.	-
Total Phosphorus Digestion	R.J Hill	Acid persulphate digestion.	-
Total Nitrogen	R.J Hill	Calculation: TKN + Nitrate-N + Nitrite-N. Please note: Default Detection Limit of 0.05 g m^{-3} is only attainable when the TKN has been determined using a trace method utilising duplicate analyses. In cases where the Detection Limit for TKN is 0.10 g m^{-3}, the Default Detection Limit for Total Nitrogen will be 0.11 g m^{-3}.	0.05 g m^{-3}
Total Ammoniacal-N	R.J Hill	Saline, filtered sample. Phenol/hypochlorite colorimetry. Discrete Analyser. (NH4-N = NH4+-N + NH3-N). APHA 4500- NH3 F (modified from manual analysis) 22nd ed. 2012.	0.010 g m^{-3}
Nitrite-N	R.J Hill	Saline sample. Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO3- I 22nd ed. 2012 (modified).	0.002 g m^{-3}
Nitrate-N	R.J Hill	Calculation: (Nitrate-N + Nitrite-N) - NO2N. In-House.	0.0010 g m^{-3}
Nitrate-N + Nitrite-N	R.J Hill	Saline sample. Total oxidised nitrogen. Automated cadmium reduction, Flow injection analyser. APHA 4500-NO3- I 22nd ed. 2012 (modified).	0.002 g m^{-3}
Total Kjeldahl Nitrogen (TKN)	R.J Hill	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-Norg D. (modified) 4500 NH3 F (modified) 22nd ed. 2012.	0.10 g m^{-3}
Dissolved Reactive Phosphorus	R.J Hill	Filtered sample. Molybdenum blue colorimetry. Discrete Analyser. APHA 4500-P E (modified from manual analysis) 22nd ed. 2012.	0.004 g m^{-3}
Total Phosphorus	R.J Hill	Total phosphorus digestion, ascorbic acid colorimetry. Discrete Analyser. APHA 4500-P B & E (modified from manual analysis) 22nd ed. 2012. Also modified to include the use of a reductant to eliminate interference from arsenic present in the sample. NWASCA, Water & soil Miscellaneous Publication No. 38, 1982.	0.004 g m^{-3}

APPENDIX 6. 2017/18 DETAILED RESULTS

Water quality and subtidal sediment site locations, Waikawa Estuary, 6 March 2018

Waikawa	Site X (lower)	Site Y (mid)	Site Z (upper)
NZTM E	1781148	1781524	1782085
NZTM N	5493426	5493722	5494425

Water quality results for upper estuary Sites X, Y and Z, Waikawa Estuary, 6 March 2018

Parameter	Units	Waikawa Site X (bottom)	Waikawa Site X (surface)	Waikawa Site Y (bottom)	Waikawa Site Y (surface)	Waikawa Site Z (bottom)	Waikawa Site Z (surface)
Depth	m	1.0	0.2	1.3	0.2	2.3	0.2
Temperature	degrees C	22.0	22.0	23.1	21.6	21.9	20.2
Salinity	ppt	18.3	9.9	30.7	5.9	28.2	2.7
Secchi depth	m	0.8	-	0.7	-	0.8	-
Dissolved Oxygen	mg l^{-1}	7.0	6.5	7.0	6.5	5.3	6.2
Chlorophyll *a*	mg m^{-3}	2.4	1.6	6.0	1.3	3.9	1.3
Total Nitrogen	g m^{-3}	0.2	0.9	0.3	0.9	0.8	1.0
Total Ammoniacal-N	g m^{-3}	0.01	0.10	0.01	0.10	0.08	0.07
Nitrite-N	g m^{-3}	0.002	0.009	0.002	0.009	0.007	0.009
Nitrate-N	g m^{-3}	0.1	0.6	0.1	0.6	0.1	0.7
Nitrate-N + Nitrite-N	g m^{-3}	0.08	0.56	0.06	0.61	0.13	0.71
Total Kjeldahl Nitrogen (TKN)	g m^{-3}	<0.2	0.3	0.2	0.3	0.6	0.3
Dissolved Reactive Phosphorus	g m^{-3}	0.01	0.02	0.01	0.02	0.04	0.02
Total Phosphorus	g m^{-3}	0.03	0.05	0.08	0.04	0.23	0.04

Sediment quality results for subtidal Sites X, Y and Z, Waikawa Estuary, 6 March 2018

Parameter	Unit	Site X	Site Y	Site Z
Dry matter of sieved sample	g/100g as rcvd	78	46	68
Total Recoverable Phosphorus	mg/kg dry wt	280	760	440
Total Nitrogen	mg/kg dry wt	<500	2100	700
Total Organic Carbon	g/100g dry wt	0.1	3.0	1.1
Mud	g/100g dry wt	1.6	68.4	37.1
Sand	g/100g dry wt	98.4	29.6	62.9
Gravel	g/100g dry wt	< 0.1	2	< 0.1
aRPD	cm	>3	1	1
Vegetation	species/% cover	- (0 %)	- (0 %)	- (0%)
Photo		Yes	Yes	Yes

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